TEXTILE RESEARCH JOURNAL

VOLUME XXVII July 1957 *NUMBER 7*

PUBLICATION OF

TEXTILE RESEARCH INSTITUTE

Publications Department: P. O. Box 625, Princeton, N. J.

TEXTILE RESEARCH JOURNAL

VOL. XXVII, NO. 7 JULY 1957

IN THIS ISSUE

ELECTROSTATIC PROPERTIES OF FINISHED CELLULOSE ACETATE YARN. G. J. Sprokel 501

INFLUENCE OF IONIZING RADIATIONS ON WOOL FIBER PROPERTIES. R. A. O'Connell and M. K. Walden 516

A STUDY OF THE WEATHERING CHARACTERISTICS OF COTTON FABRICS CONTAINING INORGANIC COMPOUNDS. PART II: FURTHER WORK ON COPPER-CHROMIUM TREATMENTS. G. R. F. Rose and C. H. Bayley 519

Industrial Section

RECENT PROGRESS IN POLYAMIDE AND POLYESTER FIBERS. G. M. Richardson, H. E. Stanley, and W. W. Heckert 529

National Cotton Council of America, 1957 Cotton Research Clinic

INCREASING COTTON CARDING PRODUCTION. J. F. Bogdan . . . 540

JOANNA'S REPORT ON METALLIC CARD CLOTHING. J. L. Delany . 551

THE SRRL INTEGRATED SYSTEM FOR OPENING AND CLEANING COTTON—THE OPENER-CLEANER. R. A. Rusca and R. C. Young . . 558

THE SRRL INTEGRATED SYSTEM FOR OPENING AND CLEANING COTTON—THE CARDING CLEANER AND THE INTEGRATED UNIT. George J. Kyame and William A. Latour 565

FIBER STRENGTH AS A FUNCTION OF FIBER LENGTH AND GAUGE LENGTH. K. L. Hertel 571

SLIVER EVENER FOR ROVING FRAMES. Hugh M. Brown and John S. Graham 579

SOME PHASES OF OPENING AND PICKING EVALUATION. W. K. Dana 584

Letters to the Editor

SOME OBSERVATIONS ON THE CHEMICAL ANTIFELTING REACTION FOR WOOL. Christopher Earland 587

BOOK REVIEWS 589

Editor: **Julian S. Jacobs** *Production Editor:* **Ellen Vogel**

Associate Editors

H. J. Ball **W. J. Hamburger** **Harold P. Lundgren**
Earl E. Berkley **Milton Harris** **H. Mark**
Henry Eyring **K. L. Hertel** **E. R. Schwarz**

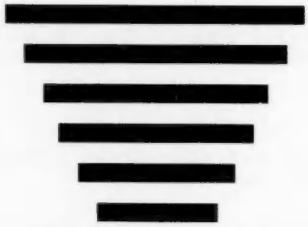
TEXTILE RESEARCH JOURNAL, published monthly at Prince and Lemon Streets, Lancaster, Pa., is devoted to the interest of research in textile and allied industries. It is published by Textile Research Institute.

Entered as second-class matter, April 27, 1945, at the post office at Lancaster, Pa., under the Act of August 24, 1912. Accepted for mailing at special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized May 9, 1950.

Manuscripts and communications should be sent to the Publications Department, P.O. Box 625, Princeton, N. J.

Subscription rates: $20.00 per year; additional for postage, 50 cents to Canada, $1.00 to all other countries. Single copies, $2.00 each.

Contents copyrighted © 1957 by Textile Research Institute. Advertising rates supplied on request.



MICROSCOPIST

Degree in science with 2 to 5 years' experience in microscopy, preferably textile microscopy.

To examine and analyze fibrous or textile material and to interpret findings and make recommendations on further research investigations.

Excellent opportunity in expansion of Celanese's research program. Please send resume, including salary requirements, to G. M. Hewitt.

Celanese CORPORATION OF AMERICA

Summit, New Jersey

TEXTILE RESEARCH JOURNAL

VOL. XXVII, NO. 7 JULY 1957

Electrostatic Properties of Finished Cellulose Acetate Yarn[1]

G. J. Sprokel

Research and Development Division, American Viscose Corporation, Marcus Hook, Pa.

Abstract

Instruments are described to measure the resistance of yarn samples and the charge build-up on the yarn as it is rubbed against a metal post. The resistance of acetate yarn can be calculated from the specific conductivity of the finish solution; the resistance of rayon yarn is much lower and is more affected by the yarn itself. The resistance of the sample determines how fast charge can leak off. If the resistance is smaller than 10^{12} or 10^{13} ohms/in., charge cannot be detected at some distance from the point of generation. The generation of the charge is not well understood. A quantitative relation does exist between the charge on the yarn and the angle of wrap and the yarn tension. It is very desirable that the antistatic agent help to spread the finish solution over the yarn surface.

Introduction

Since the advent of the new synthetic fibers, a great many papers dealing with the static behavior of these fibers have appeared. Among others, the work of Gonsalves [1, 2], Hayek [3, 4], Hearle [5, 6, 7, 8, 9, 10], and Hersh [11, 12, 13] should be mentioned. The reader is referred to these papers for a summary of the older literature.

In principle the problem is always the same; if traveling yarn rubs against a post or a guide, electric charges build up on the yarn and interfere with normal textile operations. The charge can be made to leak back to the generator by applying a sufficiently conductive finish to the yarn. Radioactive and high voltage "static eliminators," sometimes used to discharge the yarn, operate on a different principle. The air in the vicinity of these devices is strongly ionized, and the charged yarn passing through this ionized air attracts ions of opposite sign and thus is neutralized.

The trend has been to provide better leakage paths along the yarn in the form of "antistatic" finishes. In this paper, an attempt has been made to correlate the electrochemical properties of a finish with its effectiveness as an antistatic agent.

Finish is defined here as a solution of an "antistatic agent" in mineral oil. Often a third component, called coupler, is needed as a mutual solvent. Hayek [4] has listed compounds which show antistatic properties; in the present work, salts of amines, quarternary ammonium salts, condensation

[1] Paper presented at the Gordon Research Conference, New London, N. H., July 9, 1956.

products of amines and polyoxyethylene, and phosphates and phosphoric esters were studied. As couplers, sorbitol fatty esters are in common use.

Acetate yarn was used almost exclusively during this work since it is readily available at this laboratory. Most of the following should be applicable to other fibers of a hydrophobic nature. Rayon is not a very suitable fiber for the study of frictional electricity since it will generate charge only under extremely dry conditions.

In this paper a simple mathematical relation is first derived between the electrical resistance of a finished yarn and the mobility of the ions in the finish solution and their concentration. Equipment for measuring yarn resistance and finish conductivity is then discussed briefly. The results obtained with these instruments substantially verify the theory. The yarn resistance is found to be affected by the water content of the finished yarn; the antistatic properties of certain finishes are merely the consequence of their tendency to absorb moisture.

A general quantitative theory on the generation of charge does not exist. Equipment was developed to measure the charge built up on the yarn by the friction between running yarn and a metal post. This charge detector is next discussed, more fully since instruments of this kind are not normally encountered in textile research laboratories. Levels of charge on the yarn were recorded to establish the effects of the yarn resistance, the angle of wrap on the charging pin, and the yarn tension upon the intensity of yarn electrification. The charge on the yarn is shown to decrease with decreasing yarn resistance; as the resistance drops below 10^{12} or 10^{13} ohms per linear inch, the amount of charge accumulated on the yarn is found to become negligible.

The charge detector referred to above is essentially an alternating current device with a long time constant. The records of yarn charge it yields are really recordings of charge-level variations. These traces can be used for calculation of the actual charge on a short length of yarn, but the procedure is tedious and time-consuming. In the last part of the paper, apparatus is described to establish a pattern of charged segments on the yarn. The charge on the segments is recorded as a series of pulses from which the average charge and the distribution of the charge along the yarn can be obtained automatically. The two methods are shown to agree substantially.

Methods and Apparatus

1. *The Resistance of Finished Yarns*

Applying about 0.2% of a good antistatic agent dissolved in mineral oil to acetate yarn decreases the resistance of the yarn about 10,000 times. For all practical purposes, therefore, the contribution of the yarn to the transport of electricity can be neglected compared with the contribution of the finish. The resistance of a given length of coated yarn can then be computed from the specific resistance of the finish layer.

Consider a cylindrical monofilament of length l cm. and radius r cm. Let the finish layer on this cylinder be Δr cm. thick.

The resistance of the layer can be expressed as

$$R_{\text{fil}} = \frac{l\rho}{2\pi r\,\Delta r} \tag{1}$$

in which ρ is the specific resistance of the finish.

To express R_{fil} in quantities more common to the textile trade, note that

$$2\pi r\,\Delta r\,d_{\text{fin}} = \frac{p}{100}\cdot\frac{D_{\text{fil}}}{9\times 10^5} \tag{2}$$

in which d_{fin} is the density of the finish solution, D_{fil} is the denier of the monofilament, and p is the percentage of finish on the filament.

Inserting (2) in (1) and taking $l = 2.54$ cm., one obtains

$$R_{\text{fil}} = 2.3\times 10^8\,\frac{\rho\,d_{\text{fin}}}{p\,D_{\text{fil}}}\ \text{ohms/in.} \tag{3}$$

Now consider a yarn consisting of n such filaments. Assuming that each filament is uniformly covered with finish, the resistance R of the bundle of n filaments (n parallel resistances) is

$$R_{\text{yarn}} = \frac{l}{n}\,R_{\text{fil}} = \frac{l}{n}\cdot 2.3\times 10^8\,\frac{\rho\,d_{\text{fin}}}{p\,D_{\text{fil}}} \tag{4}$$

Since

$$n\,D_{\text{fil}} = D_{\text{yarn}} \tag{5}$$

we have

$$R_{\text{yarn}} = 2.3\times 10^8\times\frac{\rho\,d_{\text{fin}}}{p\,D_{\text{yarn}}} \tag{6}$$

Equation 6 is identical with (3); thus the resistance of a finished yarn is the same as that of a mono-

filament of equal total denier, covered with the same total amount of finish. Clearly, resistance measurements cannot be used to find the distribution of finish over the cross section of the yarn.

Note that in the argument above, ρ is the specific resistance of the finish film on the yarn, and that ρ need not, *a priori*, be the same as the specific resistance of the finish solution before it was applied to the yarn. For instance, if the antistatic agent were absorbed on the yarn surface, ρ would be higher than the specific resistance of the bulk solution.

To test Equation 6, equipment was designed to measure the resistance of yarn samples and the specific resistance of the finish solution applied to the yarn.

2. *Apparatus for Measuring Yarn Resistance*

Electrical circuits for measuring the resistance of yarn samples, as described by various authors, are much alike.

In the instrument used in this work, a known, high negative voltage (V_1) is applied to one end of a yarn sample (resistance R_y) and a known, adjustable low positive voltage (V_2) is applied to one end of a Victoreen HiMeg standard resistor (resistance R_s) of 10^8 to 10^{12} ohms. The junction of R_y and R_s is connected to an electrometer, used as a null indicator. V_2 is adjusted to make the deflection of the meter the same as before V_1 was applied; then R_y can be found in terms of V_1, V_2 and R_s. By Ohm's law, we find

$$R_y = \frac{V_1}{V_2} R_s$$

A simplified schematic diagram of the apparatus is given in Figure 1. The recorder shown in Figure 1 aids in balancing the bridge circuit.

The maximum practicable value of V_1 is of the order of 1000 volts. V_2 can be set with fair accuracy as low as 0.01 volt. The maximum practicable value of R_s is 10^{12} ohms. These values determine the maximum measurable value of R_y at 10^{17} ohms.

Efforts to increase this maximum much beyond 10^{17} ohms have been unsuccessful. V_1 cannot be increased to, say, 10 kV since corona effects at this high voltage may invalidate the results. V_2 can not be decreased substantially, as 10 mV is already close to the drift level of the d.c. amplifier. The resistance R_s is the grid resistor of the electrometer

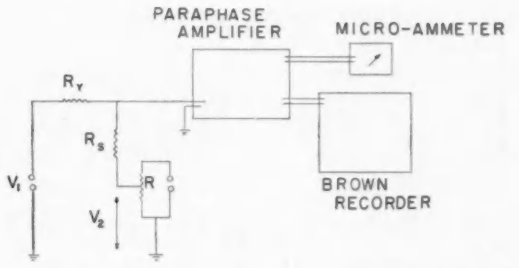


Fig. 1. Schematic diagram for measuring the resistance of yarn samples. V_1 stabilized high voltage supply. R_y yarn sample. R_s Victoreen Hi Meg resistors 10^8–10^{12} ohms. R precision potentiometer.

tube (a Victoreen 5803 electrometer triode). If a 10^{13} standard resistor is used, the reproducibility of the measurement is greatly impaired, probably because the grid current of these electrometer tubes is of the order of 10^{-13} amp. Thus, the effective value of the standard resistor is some fraction of 10^{13} ohms, depending on the momentary value of the grid current. For a 10^{12}-ohm resistor, the effect of the grid current can be neglected.

There is sufficient overlap in the ranges of the instrument to allow any yarn sample (up to 10^{16} ohm) to be measured on more than one range. Any value of the high voltage V_1 can be selected (up to 1000 V). Statistical analysis of a large set of data indicated that the apparatus can duplicate any measurement on one sample within 10%, regardless of range or high voltage setting.[2]

3. *Apparatus for Measuring the Conductivity of Oil Solutions*

The conductivity of an aqueous electrolytic solution is always measured using an a.c. voltage source of about 1000 cps, a Wheatstone bridge circuit, and an a.c. null indicator. As is well known, using a.c. avoids complications caused by polarization of the electrodes in the conductivity cell. The cell used in this work was calibrated in this way, using standard KCl solutions. The cell constant is 0.23 cm.$^{-1}$.

The standard a.c. method cannot be used for finish solutions in mineral oil as the d.c. resistance is of the same order of magnitude as the capacitive reactance of the cell filled with oil. On the other hand, the effect of polarization is very small with

[2] Hearle [9] found that for some textiles the resistance of the yarn sample depends on the voltage drop across it.

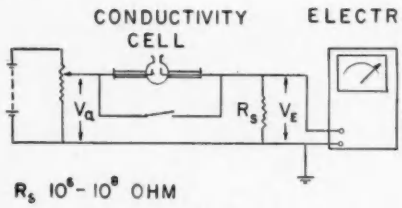


Fig. 2. Schematic diagram for measuring the specific resistance of oil solutions.

oil solutions since the current through the solution is very small.

The circuit of Figure 2 is used to measure the resistance of a finish solution. With the switch closed, the electrometer measures the applied voltage, V_a. In the open position the drop across R_s, V_0, is measured. Values of R_s can be switch-selected; the most commonly used values are 10^6 to 10^8 ohms. The input resistance of the electrometer is 10^{12} ohms, thus loading by the electrometer is negligible.

The specific resistance ρ of the solution is computed from

$$\rho = \frac{1}{0.23} R_s \frac{V_a - V_0}{V_0} \qquad (7)$$

V_a can be set between 0.5 and 50 volts. Within this range the specific resistance does not depend on the applied voltage for most finishes, nor is there a time effect. If polarization occurs, Equation 7 cannot be used; the specific resistance calculated from (7) increases as V_a is decreased. However, the effect is noticeable only if V_a is small, and adequate data may be obtained by setting V_a at 5 volts or above.

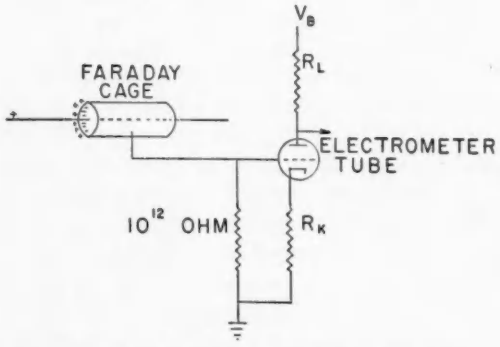


Fig. 3. Simple electrometer tube circuit for measuring charge on running yarn.

4. *Preparation of Yarn Samples for Resistance Measurement*

All samples were 75–20 acetate, spun with production-type equipment. The finish solutions were applied immediately after spinning, before the yarn was put on a bobbin. For each antistatic agent studied, several finish solutions were prepared, differing only in the concentration of the agent. The applicator was adjusted to keep the total amount of finish solution on the yarn between 2 and 3% (by weight). In this way, a set of 6 to 10 bobbins was obtained for each antistatic agent studied; all yarns carried about the same total amount of finish but different amounts of antistatic agent. The concentrations of the agent in the finish solutions were such as to apply between 0.01 and 0.5% agent to the yarn.

All the yarn samples were analyzed for total finish content. The amount of antistatic agent present was computed from these data. A quantity of yarn of the order of 3000 m. is needed for finish analysis but resistance can be measured on a sample of the order of 1 cm. It was found that there are significant differences in resistance among such short samples taken from a single bobbin. Rather than make many measurements and compute their average, a sample holder was designed such that one measurement would represent an average over a reasonable length of yarn. The sample holder consists of two brass posts rigidly mounted in Rexolite.[3] The distance between the centers is accurately 1 in. Around the posts, 2 to 2.5 m. of yarn can be wound in such a way that the yarn touches only the posts. Electrical contact is secured by putting a thin layer of a conducting glue on the outside of the posts.

Electrically the 1-in. pieces are in parallel. The instrument measures a resistance R given by

$$\frac{1}{R} = \sum_1^n \frac{1}{R_i} \qquad (8)$$

where R_i is the resistance of the ith 1-in. length of yarn and n is the total number of 1-in. lengths,

[3] Rexolite is a trade name for a modified polystyrene obtainable from Rex Corporation, Mass. The product has very good insulating properties. The resistance of a Rexolite surface immediately after cutting with a clean tool is more than 10^{17} ohms/in. If the surface is not touched or exposed to very high humidities, it will keep this value for a long time. The surface can be cleaned again by scraping with a knife, not by using organic solvents.

usually between 50 and 100. An average value of the resistance of a 1-in. length, $\bar{R}$, is obtained by multiplying R by n.

In this method of averaging, a spot not fully covered with finish has little effect on the average, while if all of the R_i were in series, the effect of the spot not fully covered would be paramount and $\bar{R}$ would not be a fair average. On the other hand, $\bar{R}$ is not the average over a full bobbin. Statistical analysis of a large set of data showed that values of $\bar{R}$ for two samples taken from different parts of a single bobbin can be expected to differ by a factor as great as 2.5. Two of the 1-in. lengths in one sample can be expected to differ by a factor as great as 15. The method of averaging removes the major part of the spread, and $\bar{R}$ can be used to characterize the yarn on a bobbin if possible fluctuations are borne in mind.

5. *The Generation and Detection of Charge on Traveling Yarn*

The method for generating charge on the yarn by friction and subsequent detection of this charge is, briefly, as follows:

Yarn taken from a bobbin is put under slight tension by a yarn brake. The friction in the brake generates charge in an uncontrollable manner. This charge is removed by passing the yarn through a brass tube coated on the inside with polonium. The now "dead" yarn is charged again by rubbing over a friction post, under controlled conditions. Without touching any other surface, the yarn travels through a Faraday cage. The charge on a small length of yarn induces a charge on the cage. The cage and the wiring form a small capacitor; the change in potential across this capacitor is amplified and recorded. The tension in the yarn can be measured after the yarn has passed through the Faraday cage, using the familiar Statham gauge and Brush Recorder. Finally, the yarn is wound on a reel.

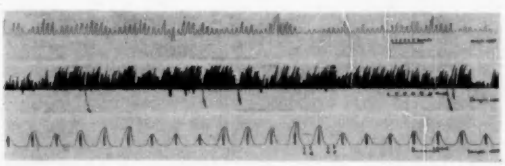


Fig. 4. To illustrate the pulse height distribution method. Yarn is discharged at regular intervals; each peak corresponds to the total charge on a small segment of yarn.

The apparatus is similar to the one described by Gonsalves [2]; the main difference is that our apparatus measures charge distribution rather than the average charge on a long sample. The apparatus simulates plant conditions better than Hersh's [1] apparatus.

The Faraday cage is made of $\frac{1}{2}$-in. brass tubing cut to any length from $\frac{1}{16}$ to 5 in. A short electrode will pick up less charge than a long one, but it will reproduce the charge distribution more closely. The Faraday cages can be quickly interchanged.

Grounded shielding rings cut from the same $\frac{1}{2}$-in. brass tubing may be mounted, coaxially, on each side of the cage electrode. Positioning the shielding rings very close to the electrode practically eliminates the effect of charge on the yarn outside the

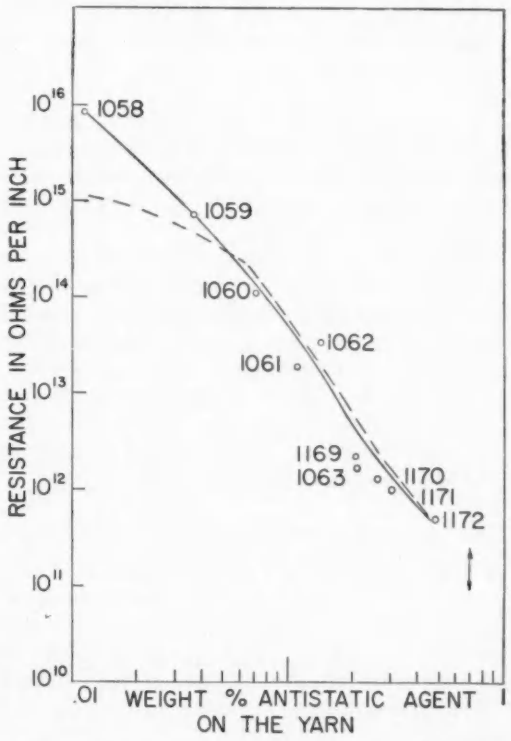


Fig. 5a. Yarn resistance in ohms per linear inch versus amount of antistatic agent on the yarn. The agent is an ethyl sulfate salt of an amine. Solid line is experimental yarn resistance. Dotted line is yarn resistance data calculated from the specific resistance of the bulk finish solution.

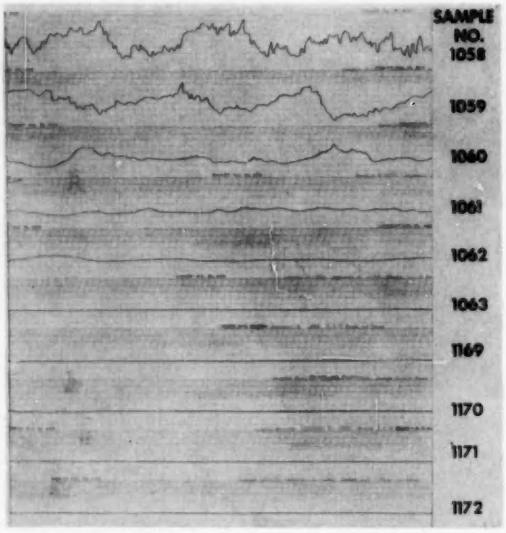


Fig. 5b. Brush chart traces representing the charge along the yarn.

cage, but the increase in capacitance of the cage to ground decreases the sensitivity of the instrument. An aluminum shield surrounding the electrode assembly prevents stray electric fields from reaching the Faraday cage.

The input signal (the potential of the Faraday cage with respect to ground) is amplified in a paraphase amplifier until the signal is sufficient to drive a Brush Penmotor. The operating controls of the instrument have been kept as simple as possible. A balance control adjusts the position of the pen of the Brush Recorder, a range switch selects the gain of the amplifier. Figures 5 and 6 illustrate the type of recordings obtained in this way.

6. *Analysis of the Operation of the Charge Detector*

The simple circuit in Figure 3 is presented here to illustrate the operation of the charge detector. The input circuit of the electrometer used in this work is more complicated, but the principle of operation is the same. The complicated circuitry is necessary to obtain a useful linear range of operation.

The outside of the Faraday cage is connected to the grid of an electrometer tube and to the grid resistor. The cage is mounted on an insulator; the leakage resistance across this mounting material is

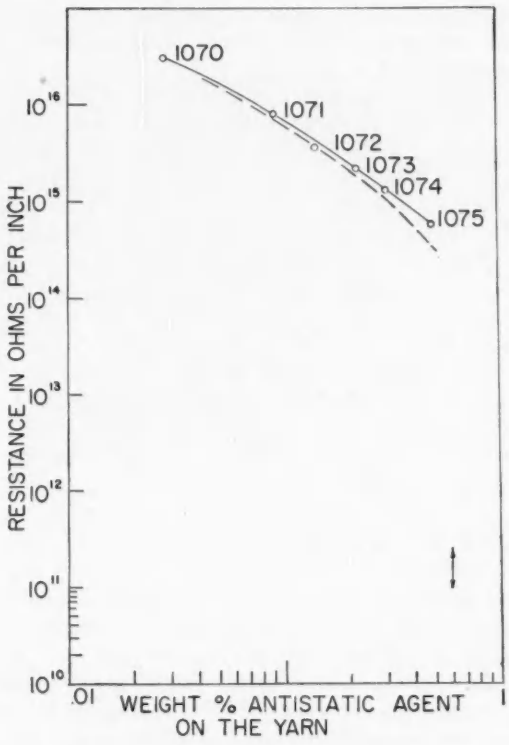


Fig. 6a. Yarn resistance in ohms per linear inch versus amount of antistatic agent on the yarn. The antistatic agent is a phosphoric ester. Solid line is experimental yarn resistance. Dotted line is data calculated from the specific resistance of the bulk finish solution.

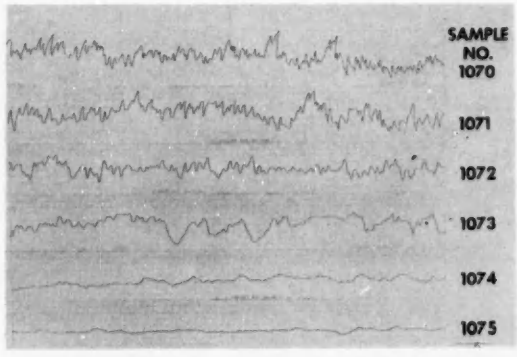


Fig. 6b. Brush chart traces representing the charge along the yarn.

orders of magnitude higher than the grid resistor of the electrometer tube and can be neglected.

Suppose a positively charged body is brought into the cage, without touching the inner surface. A negative charge is induced on the inside of the cage, and a positive charge appears on the outside. This positive charge on the outside of the cage leaks off to ground through the grid resistor but the negative charge on the inside remains as long as the charged body is inside the cage.

At any instant, the current through the grid resistor is proportional to the charge on the outside of the cage at that instant. The voltage across the grid resistor, therefore, decays exponentially in time. Hence, the insertion of a charged body will result in an initial deflection proportional to the charge, followed by an exponential decay of the deflection to zero.

If now the charged body is removed from the cage, the field inside the cage collapses and the negative charge moves to the outside. This negative charge is then neutralized by a back current through the grid resistor. The electrometer registers a peak of negative potential followed by an exponential decay to zero. The potential-time curves are mirror images. The combination of Faraday cage, electrometer and amplifier is thus a device which responds to changes of the sign and magnitude of charge of whatever body is inside the cage.

The charged body in the above argument is the charged yarn in the cage. The linear charge density along the yarn is not constant; therefore, as the yarn moves through the cage, the charge induced on the cage changes constantly while at the same time charge is leaking off from the outside of the cage at a rate proportional to the instantaneous charge on the outside. The recorder plots the voltage developed across the grid resistor as a function of time. It is desired to calculate the distribution of the charge along the yarn from this voltage-time recording.

It can be shown that, for purposes of calculation, the input circuit can be replaced by a parallel RC network, and that the electrometer and associated circuits can be regarded as a device for measuring the voltage across R at any time without disturbing the conditions existing at that time. The charge on the capacitance C is the charge on the outside of the cage. Physically, the capacitor C is the sum of the capacitance of the Faraday cage to ground, the capacitance of the wiring, and the electrometer tube input capacitance; R is the grid resistor. The time constant RC can be determined experimentally; from this C can be calculated and the instrument can be so calibrated that the deflections of the pen read changes in the charge on the cage directly in micro micro coulombs.

6a. *The Graphical Integration Method for Determining the Charge of the Yarn*

Let, at a time t, the charge on the outside of the cage be Q_t while the corresponding deflection on the Brush Chart is $V_{c,t}$. The yarn moves with a constant velocity v; in a time interval dt, a length of yarn dl $(=vdt)$ enters the cage, and an equal length leaves the cage. The linear charge density on the yarn is denoted q; q changes along the yarn and it is the function $q(l)$ we are trying to compute from the Brush chart trace. The charge on the segment leaving the cage in the time interval from t to $t + dt$ is $q(l)\,dl$, and the charge on the segment entering the cage at this time is $q(l + \lambda)\,dl$, where l is the length of yarn measured from some fixed point on the yarn and λ is the length of the cage. The net change of the charge on the yarn inside the cage is $\{q(l + \lambda) - q(l)\}\,dl$. The net change of the charge Q_t on the outside of the cage is this quantity minus that part of Q_t which leaks off through the grid resistor in the time t to $t + dt$. This part is $\frac{dQ_t}{dt}\,dt$, and from the circuit

$$\frac{-dQ_t}{dt}\,dt = \frac{-V_{c,t}}{R}\,dt \tag{10}$$

The net change in the charge on the outside of the cage in the time interval t to $t + dt$ is then

$$dQ_t = \{q(l + \lambda) - q(l)\}\,dl - \frac{V_{c,t}}{R}\,dt \tag{11}$$

Furthermore

$$dQ_t = C\,dV_{c,t} \tag{12}$$

Combining (11) and (12), we may write

$$\{q(l + \lambda) - q(l)\}\,dl = C\,dV_{c,t} + \frac{V_{c,t}}{R}\,dt \tag{13}$$

To apply this analysis to an experiment lasting from a time t_0 to t_1, it is necessary to integrate Equation 13 between these limits:

$$\int_{l_0+\lambda}^{l_1+\lambda} q(l)\,dl - \int_{l_0}^{l_1} q(l)\,dl = C(V_{c,t1} - V_{c,t0}) + \frac{1}{R}\int_{t_0}^{t_1} V_{c,t}\,dt \quad (14)$$

The left-hand side may be rewritten by separating the integrals

$$\int_{l_0+\lambda}^{l_1} q(l)\,dl + \int_{l_1}^{l_1+\lambda} q(l)\,dl - \int_{l_0}^{l_0+\lambda} q(l)\,dl - \int_{l_0+\lambda}^{l_1} q(l)\,dl =$$

The first and fourth integral cancel and the equation reduces to

$$\int_{l_1}^{l_1+\lambda} q(l)\,dl - \int_{l_0}^{l_0+\lambda} q(l)\,dl = C(V_{c,t_1} - V_{c,t_0}) + \frac{l}{R}\int_{t_0}^{t_1} V_{c,t}\,dt \quad (15)$$

which can be abbreviated to

$$Q_1 - Q_0 = C(V_{c,t_1} - V_{c,t_0}) + \frac{l}{R}\int_{t_0}^{t_1} V_{c,t}\,dt \quad (16)$$

where Q_1 and Q_0 are the changes on the segments of yarn of length λ which are in the cage at the times t_1 and t_0, respectively.

In Equation 16, the left-hand side represents the difference in charge on two segments of yarn of the same length as the Faraday cage and separated by whatever length of yarn has passed through the cage in the time interval from t_0 to t_1. The term $C(V_{c,t_1} - V_{c,t_0})$ on the right-hand side would represent the difference in charge on the two segments of yarn *if* charge had not leaked off. The integral on the right accounts for the change in the charge level of the cage which has occurred by leakage of charge through the grid resistor in time $t_1 - t_0$. The voltages V_{c,t_1} and V_{c,t_0} can be read from the Brush chart, and the integral can be computed from the area under the trace on the Brush chart. If the experiment starts with uncharged yarn in an uncharged Faraday cage, and charged yarn enters the cage at the time t_0, Q_0 is zero and Q_1 is the total charge on a known small length of yarn. Q_1 can then be computed from the Brush chart trace. The procedure could be repeated any number of times. In principle, a charge distribution curve for a particular yarn sample could be constructed from a large number of Brush chart traces of the nature described.

Equation 16 was tested in model experiments and found to be correct. For yarn samples the method can be used to calculate the average charge, with a fair degree of accuracy, from a relatively small number of tests. However, since graphical integration is very time-consuming, it would take too long to collect the data necessary for satisfactory charge distribution curves.

6b. *The Pulse Height Distribution Method*

A faster method for measuring charge distribution was next developed. The method is based on the principle that the integral in (16) can be made negligibly small compared with the $C\,V_{c,t}$ term if the time span is chosen short enough. If each measurement is started with an uncharged cage, the deflection will be proportional to the charge on the yarn in the cage. It will be clear that the Faraday cage can be discharged only by grounding the cage while uncharged yarn is passing through it. Accordingly, apparatus was designed to discharge evenly spaced small segments of yarn leaving the charge on the intervening segments of yarn in its original state. Also, it was arranged to ground the Faraday cage automatically as each uncharged length passed through it, so that as each charged segment entered, its charge was registered by the total deflection of the recorder. The Brush chart recording consists of a series of pulses rather than a continuous trace; the height of each pulse is proportional to the charge on the small segment of yarn producing the pulse.

The apparatus for discharging alternating segments of yarn is placed between the friction post, where the charge is generated, and the Faraday cage of the detector. This device consists of a $\frac{1}{2}$-in. wide metal strip wound in a 1-turn helix of about 2 in. radius, rotated by a variable speed motor. Inside the helix is a polonium-coated brass strip shielded by lead. The shield is designed to pass a long, narrow beam of radiation. The yarn travels lengthwise through the beam on the outside of the helix, close to the surface of the latter but without touching it. The motor is adjusted so that the axial velocity of a point on the helix is equal to the yarn velocity. Small lengths of the traveling yarn are shielded from the radiation by the metal helix, while much longer intervening lengths are

exposed, and the charge on the exposed parts is neutralized. As long as the axial velocity of the helix equals the yarn velocity, the pattern of charged and discharged lengths is repeated continuously. If the two velocities differ considerably, all of the charge is removed. Since the pattern of charged and discharged spots does not change during the time the yarn travels from the discharging instrument to the electrometer, the pattern can be established at a convenient distance from the electrometer so as not to disturb the input circuit.

The grounding switch must have a leakage of much more than 10^{12} ohms when open, and must close immediately after the charged part has left the cage. An electro-mechanical switch meeting these requirements was built. The timing of this switch is controlled by a microswitch and cam wheel arrangement, with the cam wheel mounted on the shaft of the variable speed motor and thus synchronized with the action of the discharging device.

Figure 4 illustrates the type of traces obtained in this way. The upper trace was run at standard chart speed; the chart speed of the middle trace was slowed down five-fold to show a longer length of yarn. In the lower trace the chart speed is five-fold faster than usual, to permit close examination of the peaks. As a charged spot approaches the neutral cage, more and more charge is induced on the latter; a maximum is reached as the entire length of the spot is inside the cage, and the charge registered then decreases as the yarn moves on. After the spot has left the cage the grounding switch is closed; it is opened again just before the next charged spot arrives.

The charged spot represents 200–250 msec. of yarn travel. The base of the peak is betweeen 500 and 600 msec. During this time, not more than 2% of the induced charge can leak off. Neglecting this leakage, the charge induced during each peak equals $C\ V_{peak}$; the input capacitance, C, can readily be measured (as discussed previously) and V_{peak} can be read from the recording. From a large number of peaks, a charge distribution curve can be constructed, simply by taking the fractions of the peaks within each of a chosen set of voltage subranges and plotting these fractions as ordinate, against voltage as abscissa. Traces like number 2 in Figure 4 could very well be used for obtaining such a charge-distribution curve.

6c. *The Pulse Height Analyzer*

To eliminate the counting of peaks of various heights on Brush charts, as described above, a pulse height analyzer was next constructed. The heart of the analyzer is a Brush pen motor, identical with the one used to make the recordings. The pen of the motor was replaced by a thin rod with a tiny wheel at its end. The wheel rolls across a set of 35 strip contacts, each 0.03 in. wide and insulated from its neighbors by strips of polyethylene film. Each contact is connected to its relay and counter.

The output signal of the electrometer drives the pen motor; its deflection is proportional to the charge on the cage at all times. As explained above, the maximum deflection represents the charge on the yarn segments; therefore, a count should be made at this maximal deflection only. To achieve this, the counter circuits are turned on by an energizing pulse for the duration of this pulse only. If the energizing pulse is timed to coincide with the time of maximal pen deflection, each charge peak will thus result in one count, on the counter corresponding to the height of the peak. If a sufficient number of counts is made the charge distribution can be read from the counter dials.

The timing of the pulse energizing the counter circuit is critical, but a second Brush recorder can be used for visual alignment. Trace number 3 of Figure 4 was made as a routine check on the operation of the instrument before a yarn sample was tested. The alignment is as good as can be obtained; the marker pips, representing the energizing pulse are about 40 msec. wide and coincide with the tops of the charge pulses. The energizing pulse is wide enough to assure that a count will be made.

6d. *Calibration*

As explained before, from the input capacitance and the voltage gain of the detector, the charge represented by one peak can be calculated. This charge is equal to the total charge on one segment of yarn; however, the length of the segments can be approximated only from the geometry of the discharging device. If it is desired to express the charge on the yarn as charge per unit length, the length of a segment must be known.

The charge computed in the graphical integration method represents, to a better degree of approximation, the charge on a segment of yarn equal to

the length of the Faraday cage. Therefore, the pulse height analyzer was calibrated by comparing the average charge per segment, as calculated from the counter data for a number of yarn samples, with the average charge per unit length of yarn, as calculated by the graphical integration method for the same samples of yarn.

Results and Discussion

7. *The Correlation between Resistance and Charge*

In the course of this work about 1 doz. antistatic agents were studied; in Figures 5 and 6, results are shown representing a group of ionic, nonhygroscopic agents and a group of non-ionic, nonhygroscopic agents, respectively. The agent in Figure 5 is an amine salt; the agent in Figure 6 is a phosphoric ester.

In Figures 5a and 6a, the resistance of the yarn in ohms per linear inch is plotted against the antistatic agent concentration on the yarn. Data were obtained using the sample holders discussed in Section 4; the accuracy of the data is indicated on the graphs. The experimental points are joined by a solid line.

Also plotted on the graphs are the calculated resistances of 1-in. lengths of yarn, computed from the bulk conductivity of the finish and the finish concentration using Equation 6. The calculated points are joined by a dotted line.

The curves coincide within experimental error, proving that the basic assumptions underlying Equation 6 are correct. The agents are not strongly absorbed at the cellulose-acetate oil interface but retain their mobility in the oil film on the yarn.

In general, it was found that the resistance of yarn finished with ionic agents decreases sharply as the concentration of the agent on the yarn is increased. The resistance of yarn finished with non-ionic agents decreases much less with increasing agent concentration; non-ionics still conduct electricity, however, probably because of ionic impurities.

The resistance of yarn finished with 0.01% of an ionic agent usually is of the order of 10^{16}–10^{17} ohms/in.; at 0.5% agent concentration, the resistance has dropped to around 10^{11}–10^{12} ohms/in. The resistance of yarn with 0.01% of a nonionic agent is about 10^{16}–10^{17} ohms/in., dropping to about 10^{14}–10^{15} ohms/in. at 0.5% agent concentration.

In Figures 5b and 6b, recordings of the charge on the same yarn samples are presented. The numbers on the recordings correspond to the sample numbers on the graphs in Figures 5a and 6a, respectively.

For ionics the amplitude of the charge peaks decreases rapidly as the antistatic agent concentration on the yarn is increased; a concentration is reached beyond which charge cannot be detected. For the agent represented in Figures 5a and 5b, this threshold concentration is between 0.15 and 0.2%.

Quite generally it was found that the antistatic agent concentration at which charge cannot be detected is the concentration corresponding to a yarn resistance of about 10^{13} ohms/in. Consequently, if this 10^{13} ohms/in. level of conductance is not reached, the yarn will generate charge, as is demonstrated in Figure 6b where at 0.5% anti-

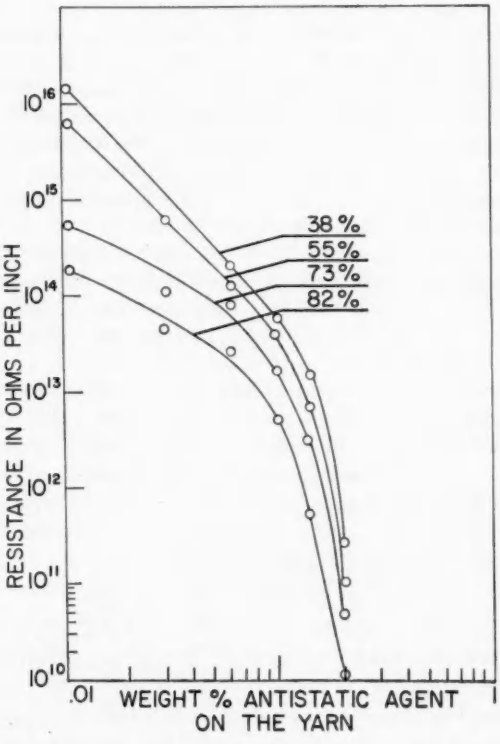


Fig. 7. Resistance of the yarn versus amount of agent on the yarn at four levels of humidity. The agent is a quaternary ammonium salt.

static agent the yarn resistance is still 5×10^{14} ohms/in.

The 10^{13} ohms/in. limit is of course an approximation; second order effects such as differences in finish lubricity (which may effect the charging process) are not taken into account, but the correlation is certainly not mere coincidence and not an artifact of the instruments used. If conditions are changed such that the friction between yarn and post is increased, it is found that higher charges are built up on the yarn, but yarn samples of, say 10^{12} ohms/in., that generate no static under milder conditions, still do not generate charge even if the friction is increased to the point of breaking the yarn.

The specific resistance of the finish solution needed to bring the yarn resistance down to the 10^{13} ohm/in. level can be calculated from Equation 6; for 100-den. yarn, the specific resistance is of the order of 10^7 ohm cm.

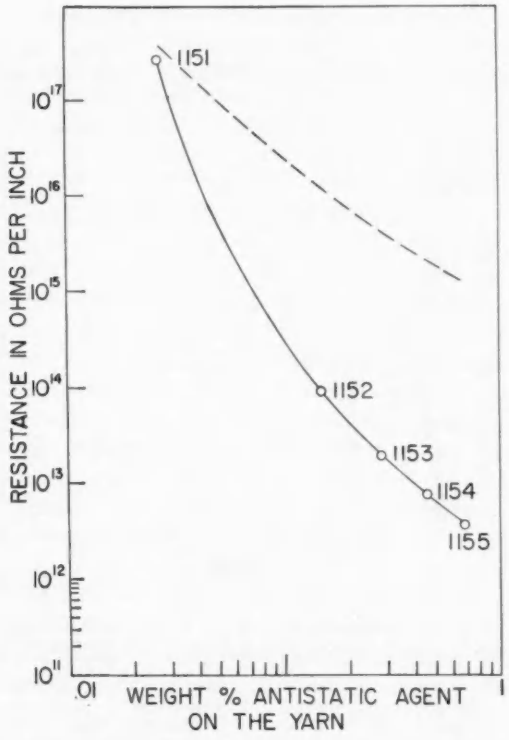


Fig. 8. Resistance versus amount of agent on the yarn. The agent used is non-ionic and hygroscopic. Dotted line is calculated from the specific resistance of the dry bulk solution. Solid line is experimental yarn resistance.

8a. *Yarn Resistance and Relative Humidity—Acetate Finishes*

The humidity in the test room can be maintained at any point between 40 and 80% R.H. at normal temperatures. If not indicated otherwise, the samples were conditioned and the tests carried out at 40% R.H. and 75° F. In general, the resistance of finished yarn decreases as the relative humidity is increased, but the magnitude of the effect depends on the chemical nature of the finish.

In Figure 7, the yarn resistance is plotted against the concentration of the agent on the yarn for four different levels of humidity. The agent used is a quaternary ammonium salt, here representing a group of ionic, nonhygroscopic agents. For samples having only a very small amount of finish, increasing the relative humidity from 40 to 80% decreases the resistance by a factor of 100; for normal finish concentrations, the decrease is by a factor of about 50. The effect is quite respectable though not as large as the effect of the finish concentration. As can be verified from the graphs, increasing the finish concentration from 0.01 to 0.15% decreases the resistance by a factor of 50,000.

In Figure 8, results are shown for a non-ionic hygroscopic agent, in this case a diamine coupled with ethylene oxide. The data in the graph refer to yarn and finish samples conditioned at 40% R.H. The calculated curve is similar to the curve for the non-ionic agent in Figure 6a, but the experimental curve is much steeper, indicating that the finish layer conducts better than the bulk of the finish solution. If the finish solutions, put in shallow disks, are conditioned at nearly 100% R.H. for about a day, the specific resistance of the solutions decreases sharply. The specific resistance data for the "wet" solution agree with the experimentally determined yarn resistance data.

Immediately after spinning, acetate yarn contains of the order of 5% water. One may account for the discrepancy noted in Figure 8 by assuming that some of this water enters the finish layer; thus the finish layer contains more water than the bulk finish solution.

If the wet finish solutions are dried at 105° for 1 hr., the specific resistance increases somewhat but the original dry level cannot be reached, as pro-

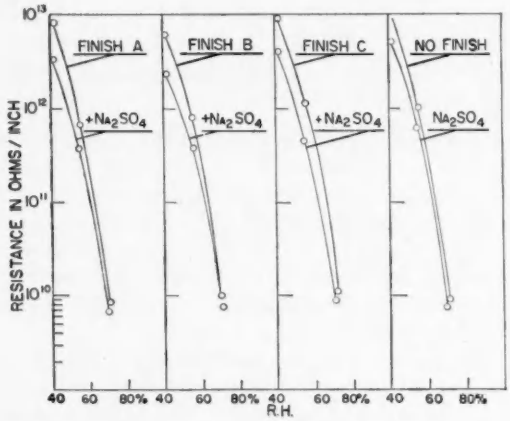


Fig. 9. Resistance of viscose rayon samples finished with different agents as a function of the relative humidity. Finish *a* is a standard rayon finish. Finish *b* is the finish discussed in Figure 5. Finish *c* is a modern acetate finish.

longed drying at 105° causes thermal degradation. This is in agreement with the fact that the finish layer on the yarn retains its water even if the yarn is stored for weeks at 40% R.H.

Incidentally, if the finish solutions are left in the wet atmosphere for a few days, they separate into an oil and a water layer. The agent has absorbed so much water that the coupler can no longer keep it in the mineral oil.

Clearly this hygroscopic non-ionic type of finish depends for its action on its tendency to absorb moisture. The "wet" film conducts electricity much better, probably because impurities in the agent ionize in the wet finish to a greater extent.

8b. *Yarn Resistance and Relative Humidity—Viscose Rayon*

The much greater water content of viscose rayon and cotton as compared with acetate and the other synthetics may account for the fact that the cellulose fibers present no real problem of "static." In Figure 9, the resistance of finished viscose rayon yarn samples is plotted against the relative humidity at which the samples were conditioned. The samples were prepared by finishing rayon cakes with emulsions containing antistatic agent. In Figure 9a, standard rayon finish is used; 9b contains the agent discussed in Figure 5; 9c is the finish discussed in Figure 7; 9d is yarn with no finish ("hard finish"). Four other rayon cakes were finished with the same finish solutions, but 1% Na_2SO_4 was added to the bath. Comparing the graphs for finished and unfinished yarn, it is seen that the finish has negligible effect on the yarn resistance. If a small amount of sodium sulfate is added to each finish bath, the resistance of the finished yarn drops somewhat at low relative humidity but again there is no difference between yarns finished with sodium sulfate solution or with sodium sulfate plus antistatic agent. The conclusion is rather obvious: unfinished rayon, spun, washed, dried, and conditioned in the normal way contains enough water and ions to decrease the yarn resistance below 10^{13} ohms/in., at least at humidities above 40% and probably down to still lower humidities. Thus viscose rayon is not expected to show static properties and, indeed, none of the samples generated a measurable charge.

9. *Distribution Curves*

Charge distribution curves, as illustrated in Figures 10 and 11, are constructed by plotting the number of counts registered by each counter against

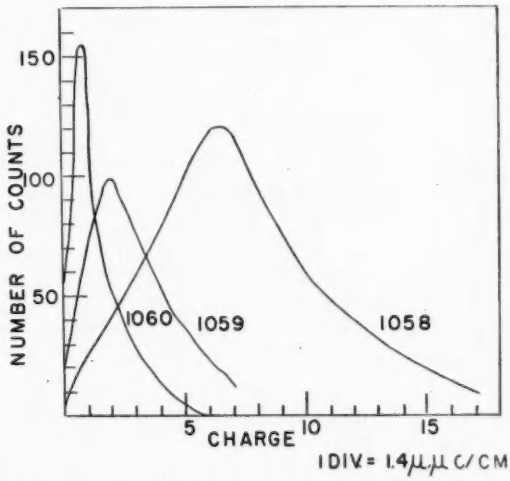


Fig. 10. Charge distribution curves for an ionic antistatic agent. Number of counts is plotted against level of charge.

Sample No.	Agent, %	Resistance, ohms/in.	Average charge, mmC./cm.
1058	0.01	10^{16}	12
1059	0.035	6×10^{14}	2.8
1060	0.06	10^{14}	1.4
1061	0.12	2×10^{13}	—

(Curve for 1061 coincides with Y axis.)

the charge level represented by that counter. For routine work the total number of counts is 1000 and represents about 40 m. of yarn. The test requires about 15 min.

The agents chosen for Figures 10 and 11 were the same as in Figures 5 and 6, respectively; the numbers on the curves correspond to the sample numbers on the graphs and on the recordings. Data for the amount of agent on the yarn, the resistance of the yarn, and the charge generated on the yarn are tabulated in Figures 10 and 11.

Yarn samples forming a concentration series were tested under identical conditions (yarn tension, angle of wrap, room humidity); the distribution curves illustrate the effect of the antistatic agent concentration. In Figure 10, representing an ionic antistatic agent, it is seen first of all that the average charge decreases rapidly to zero as the antistatic agent concentration is increased from 0.01 to 0.1%. This is not of particular interest here as the same conclusion may be drawn from visual inspection of the continuous Brush recordings in Figure 5. More striking is the wide spread in the charge distribution for samples carrying a very small amount of finish (0.01%) and the sharp decrease in the number of spots that carry a high charge as the antistatic agent concentration is increased from 0.01 to 0.03%.

It appears probable that the mechanical applicator does not cover every spot on the yarn with finish solution. Following this hypothesis, we would say that the yarn has blank spots, and spots covered with finish but isolated from other covered spots by blank yarn. The charge generated on a blank spot is stationary in the time span under consideration; charge generated on an isolated covered spot spreads evenly over the surface of the spot but cannot leak away from that spot. It is recalled that all yarn samples have the same total amount of finish; only the amount of antistatic agent is different. As the agent concentration is increased, the number of blank spots and isolated covered spots decreases. It seems reasonable to assume, therefore, that the agent has a tendency to spread the solution out over the yarn surface. For the agent under discussion the yarn surface is assumed to be covered with a continuous finish layer at about 0.1% agent concentration. At this concentration the conductivity of the layer is sufficient to allow charge to leak back to the point of generation in a short time; at some distance from the generator the yarn is neutral.

A few preliminary laboratory experiments have shown that less agent is needed if the finish solutions are applied more evenly. In these experiments, finish was applied by immersing loosely wound yarn in a finish solution diluted with a volatile solvent.

These ideas need to be verified by measuring directly the distribution of the agent on the yarn surface. Normal analytical methods cannot be used. It is hoped that more information on this distribution can be obtained by radioactive tracer techniques.

The charge distribution for yarn finished with the non-ionic agent does not change appreciably as the concentration of the agent is increased. This may be caused by poor conductivity or by poor surfactant properties of the agent; charge distribution measurements are indecisive in this respect.

Traces of the type discussed in Figure 4 were inspected for any periodicity in the charge distribution. No regularity has been found.

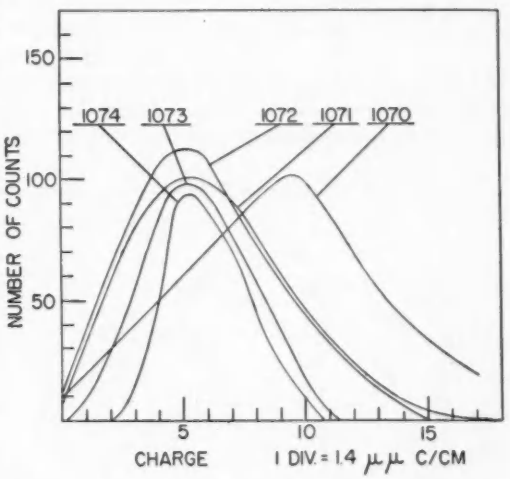


Fig. 11. Charge distribution curves for a non-ionic antistatic agent. The number of counts is plotted against the level of charge.

Sample No.	A.A., %	Resistance, ohms/in.	Average charge, mmC./cm.
1070	0.03	3×10^{16}	12.2
1071	0.09	9×10^{15}	9.6
1072	0.15	4×10^{15}	9.1
1073	0.2	2×10^{15}	7.6
1074	0.5	6×10^{14}	8.8

10. *The Effect of Angle of Wrap and Yarn Tension on the Charge Build Up*

The amount of charge on the yarn increases as the angle of wrap or the pre-tension is increased. The length of yarn in contact with the surface of the friction post is proportional to the angle of wrap; this might account for the increase in charge. However, increasing the angle of wrap increases the average normal force between yarn and post, and the same increase in normal force can be obtained by increasing the pre-tension while holding the angle of wrap constant. In the following paragraphs some experiments are discussed which were designed to separate the two effects. The pulse height analyzer was used throughout these experiments since this is the fastest method to obtain quantitative data.

The increase in tension, Δp, as the yarn passes over the friction post can readily be measured using a differential strain gauge, and Δp can be used as a measure of this friction.

Δp and charge generated cannot be measured in the same experiment. Therefore, in a preliminary set of experiments, the friction, expressed as Δp, was measured as a function of the angle of wrap and the pre-tension. Next, the charge on the yarn was measured using a series of combinations of angle of wrap and pre-tension. From the results of the preliminary experiments the corresponding increases of tension can be found, and the charge can be expressed as a function of Δp with the angle of wrap as a parameter. The angles were varied from 30° to 90°, the pre-tension was varied in such a way that Δp varies from zero to about 7 g.

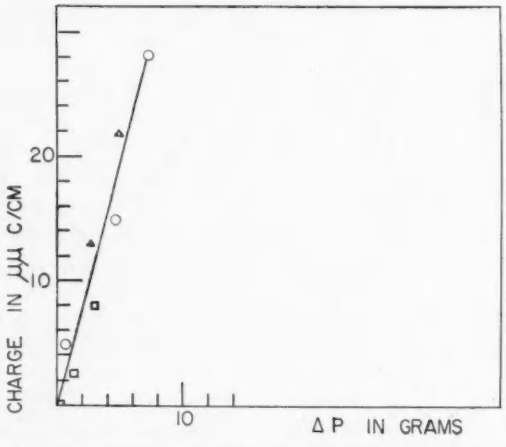


Fig. 12. Average charge in micro micro coulombs versus the increase in tension in grams. ⊙ data for 90° angle of wrap. △ data for 60° angle of wrap. ⊡ data for 30° angle of wrap.

The results are plotted in Figure 12. It may be seen that the charge increases linearly with Δp over the range of values tested, regardless of the combination of angle and pre-tension used to obtain Δp. The friction versus angle of wrap data do not fit a simple exponential expression such as, for example, $p_2 = p_1 \exp(\mu\psi)$. However, it is reasonable to assume that Δp increases as the friction between yarn and post increases. This then indicates a third way in which an antistatic agent may be effective. It may reduce the friction between the yarn and the post and thus the charge generated on the yarn.

Summary

The resistance of a yarn is a suitable parameter to describe the electrostatic behavior of that yarn, since the yarn resistance determines how fast charge generated on the yarn can leak off. If the resistance is made small enough — 10^{12} or 10^{13} ohms per linear inch — by applying a conductive coating on the yarn, charge cannot be detected at some distance from the point of generation.

The resistance of acetate yarn is governed entirely by the physicochemical properties of the applied finish. From the specific conductivity of the bulk finish solution (antistatic agent in mineral oil) and the amount of finish applied to the yarn, the resistance of the finished yarn can be calculated. If the finish solution is hygroscopic, some caution is necessary. The solution to be measured must contain the same percentage of water as the finish film on the yarn. If the finish is applied as an emulsion, the yarn resistance cannot be calculated from the conductivity of the emulsion, since this conductivity is not related to the conductivity of the oil phase.

The resistance of viscose rayon, on the other hand, is mainly determined by the yarn substance itself. The resistance depends on the amount of water and salt (Na_2SO_4) left in the yarn. For commercial yarn these amounts of water and salt are sufficient to prevent any troublesome build up of charge.

The yarn resistance and the charge accumulated on the yarn decrease as the humidity of the surrounding atmosphere is increased. Again, for fin-

ished acetate, the decrease depends on the properties of the applied finish, while for viscose rayon the finish is of minor importance.

The charge generation cannot be described quantitatively at present. More detailed knowledge about the electrical interaction of the two surfaces in contact with each other is necessary. A quantitative relation does exist between the charge generated on the yarn and the angle of wrap and the tension in the yarn.

If the finish solution applied to the yarn contains an inadequate amount of antistatic agent, the charge is quite unevenly distributed along the yarn. The resistance of small segments of such yarns shows large variations along the yarn. From these experimental facts, it may be concluded that (*a*) the finish solution is distributed quite unevenly along the yarn, and (*b*) the antistatic agent helps to spread the finish solution over the yarn surface.

Instruments for measuring the high resistance of yarn samples and the charge distribution along the yarn as developed in this laboratory are described in some detail.

Acknowledgment

The author wishes to express his appreciation to Dr. J. A. Howsmon and Mr. H. H. Hall of the Acetate Section for their kind cooperation and the preparation of yarn samples, to Dr. M. T. O'Shaughnessy for his advice and criticism, and to Dr. H. H. Cudd for permission to publish these results.

Literature Cited

1. Gonsalves, V. E., TEXTILE RESEARCH JOURNAL **23**, 711 (1953).
2. Gonsalves, V. E., and Dongeren, V. J. V., TEXTILE RESEARCH JOURNAL **24**, 1 (1954).
3. Hayek, M., and Chromey, F. C., *Am. Dyestuff Rept.* **40**, 164, 225 (1951).
4. Hayek, M., *Am. Dyestuff Rept.* **40**, 368 (1954).
5. Hearle, G. W. S., and Jones, E. H., *J. Textile Inst.* **40**, T311 (1949).
6. Hearle, G. W. S., *J. Textile Inst.* **43**, 194 (1952).
7. Hearle, G. W. S., *J. Textile Inst.* **44**, T117 (1953).
8. Hearle, G. W. S., *J. Textile Inst.* **44**, T144 (1953).
9. Hearle, G. W. S., *J. Textile Inst.* **44**, T155 (1953).
10. Hearle, G. W. S., *J. Textile Inst.* **44**, T177 (1953).
11. Hersh, S. P., and Montgomery, D. J., TEXTILE RESEARCH JOURNAL **22**, 805 (1952).
12. Hersh, S. P., Sharman, E. P., and Montgomery, D. J., TEXTILE RESEARCH JOURNAL **24**, 426 (1954).
13. Hersh, S. P., and Montgomery, D. J., TEXTILE RESEARCH JOURNAL **25**, 279 (1955).

Manuscript received December 27, 1956.

Influence of Ionizing Radiations on Wool Fiber Properties

R. A. O'Connell and M. K. Walden

Western Utilization Research Branch, Agricultural Research Service, U.S. Department of Agriculture, Albany, Cal.

Introduction

Kirby and Rutherford [1] report that neutron bombardment of wool with doses up to 10^{15} nvt did not change wool fiber properties but higher dosages caused progressive degradation; on the other hand, McGrath and Johnson [2] found that gamma radiation of 0.5 to 7.4×10^6 roentgens slightly increased the strength of wool fabric. The present study was undertaken to compare the influence of several types of radiation on certain wool fiber properties, with the possible objective of finding conditions that would significantly increase the chemical stability of wool.

The radiations employed were soft X rays, gamma rays from cobalt-60, cathode rays (from both a linear accelerator and from a Van de Graaff generator), and ultraviolet light.

The effects were evaluated by stress-strain measurements on wet and dry single fibers and by supercontraction tests in 5% sodium bisulfite solution. Although no evidence of cross-linking was observed and damage to the wool occurred in all cases, the extent of damage was small or even negligible until the samples were subjected to relatively large doses of radiation. Thus it would appear that low levels of radiation can be used safely to sterilize wool materials, catalyze polymerization reactions in wool, control static in processing, fix dyes to wool, and in other ways to facilitate textile processing.

Experimental

Except for the UV studies, samples were treated at laboratories having appropriate radiation facilities. The samples were packaged in small polyethylene envelopes and irradiated through the envelopes. The moisture regain of the samples was not controlled but may be assumed to have been in the range of 8 to 14%.

The X irradiation was done by the General Electric Corporation, Milwaukee, Wisconsin; gamma irradiation, from cobalt-60, was done at Stanford Research Institute, Palo Alto, California; cathode irradiations were performed at Massachusetts Institute of Technology with a Van de Graaff generator and at Applied Radiation Corporation, Walnut Creek, California, with a linear accelerator. UV irradiations were done in this laboratory with a General Electric Corporation 15-watt germicidal lamp (2537 Å) positioned with the fibers approximately 0.75 in. from the surface of the tube. For experiments in which humidity was controlled, the fibers were suspended in a quartz tube through which conditioned air was passed.

Stress-strain curves were obtained from single fibers after equilibration at 65% RH and 70° F. or submergence in water at 70° F. A constant rate of loading of 2 g./grex/minute (based on the grex as determined vibroscopically at 65% RH and 70° F.) was used and from these curves information was obtained on the stress to extend the fiber 30%, designated as Stress 30, and the initial modulus, designated as Young's modulus. Supercontraction tests were performed by the method of Speakman [3]; in this method the change in length of single fibers is determined after exposure for 1 hr. to 5% sodium bi-

TABLE I. Effect of X Irradiation on Wool Single Fiber Properties

Wool		Control	1	3	9×10^6 REP
A	Wet str. 30	0.46	0.44	0.41	0.35
	Wet YM	10.9	9.2	9.4	7.8
	Dry str. 30	0.95	0.92	0.92	0.85
	Dry YM	18.7	17.2	18.2	17.6
B	Wet str. 30	0.39	0.38	0.34	0.31
(Dyed)	Wet YM	7.1	7.0	6.6	6.0
	Dry str. 30	0.87	0.84	0.80	0.83
	Dry YM	16.1	14.9	15.0	15.6

sulfite solution at 96–98° C. A normal wool fiber supercontracts about 25%. The amount of supercontraction decreases if stable cross-links are introduced, so that this test serves as an index of cross-linking.

Wool A was a nonprocessed solvent-scoured Columbia wool; wool B was a Columbia X Southdale wool in top form, also solvent scoured.

Results

Stress-strain properties of the control and irradiated single fibers are presented in Tables I through III. Data are given in grams per grex and are mean values obtained from testing some 20 fibers in each case. Confidence intervals of 95% for these means are approximately as follows: for wet stress 30, $\overline{X} \pm 0.02$; wet Young's modulus, $\overline{X} \pm 0.8$; dry stress 30, $\overline{X} \pm 0.03$; and dry Young's modulus, $\overline{X} \pm 1.3$. The data show that degradation is slight until higher doses are given and that about 5 million REP (Roentgen Equivalent Physical) are required to produce perceptible damage except in the case of X rays, which appear somewhat more damaging than the other radiations.

The dyed wool was dyed with Rhodamine B, a dye generally recognized as having poor wash fastness in wool. The dyeing in itself appears to cause slight damage to the wool, indicated by the control data in the tables. Significantly, the dyed fibers are somewhat more resistant to irradiation, and with increase in time of irradiation the dye becomes difficult to remove from the fiber by washing.

Results of the UV irradiation are presented in Figure 1 as 30% Index versus time of exposure. Single calibrated fibers were employed and the 30% Index taken as the ratio of the stress necessary to extend a given fiber 30% in water after treatment to that before treatment. Each point on the curve represents the average of 10 fibers. The decrease in 30% Index is very rapid at first, in contradistinction to the effects of the high energy radiations, decreasing exponentially with time. After 7 days' exposure a value of 0.4 was found. Supercontraction tests also show progressive damage by UV, as shown in Table IV. The wools irradiated with high energy sources exhibit an increase in supercontraction only after the highest doses.

Radiation effects on fibers of different moisture contents were investigated for UV irradiation only. Calibrated single fibers were suspended in a quartz tube through which conditioned air was passed. Since the distance of lamp to fibers was not identical

TABLE II. Effect of Gamma Irradiation on Wool Single Fiber Properties

Wool		Control	2	10	25×10^6 r
A	Wet str. 30	0.48	0.44	0.40	0.39
	Wet YM	11.1	8.8	8.3	7.6
	Dry str. 30	0.97	0.90	0.88	0.87
	Dry YM	18.7	15.8	15.8	15.3
A (Dyed)	Wet str. 30	0.42	0.40	0.41	0.39
	Wet YM	9.4	8.6	8.6	8.3
	Dry str. 30	0.91	0.87	0.92	0.92
	Dry YM	17.4	17.4	17.2	18.1

TABLE III. Effect of Cathode Irradiation on Wool Single Fiber Properties

Van de Graaff

Wool		Control	4	8×10^6 REP
A	Wet str. 30	0.46	—	0.43
	Wet YM	10.9	—	9.6
B	Wet str. 30	0.41	0.42	0.40
	Wet YM	8.3	8.4	7.9

Linear Accelerator

Wool		Control	0.07	0.24	3	25×10^6 REP
A	Wet str. 30	0.46	0.46	0.47	0.46	0.34
	Wet YM	10.9	11.1	11.4	10.5	8.9
B	Wet str. 30	0.41	0.41	0.42	0.42	0.32
	Wet YM	8.3	7.8	7.9	7.8	6.4

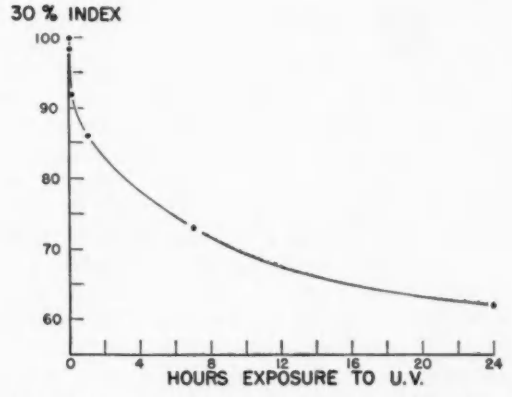


Fig. 1. Effect on 30% index of exposure of calibrated wool fibers to germicidal UV lamp.

TABLE IV. Effect of UV Exposure on Supercontraction in 5% $NaHSO_3$

UV exposure, hr.	0.1	0.25	0.5	1	3	7	24
% supercontraction	20.7	24.3	24.6	27.5	27.8	32.3	32.0

TABLE V. Effect of Humidity on 30% Index after Exposure of 1 Hr. to UV Lamp

% relative humidity	0	43	100
30% index	89.7	89.6	90.3

to that for previous experiments, the absolute values of 30% Index shown in the tables are not directly comparable. Seven fibers were irradiated at each humidity for 1 hr. Average values are presented in Table V. Although no humidity effect is noticeable, it is possible that differences in moisture content may cause differences in the effects of other types or at higher levels of radiation.

Summary

Important single fiber properties of wools irradiated with several sources of high energy radiation have been investigated. No evidence of the introduction of new cross-links into the wool was found. Although wool fibers exhibit progressive damage with increase in radiation, this damage is slight at low levels of dosage. Doses up to and equivalent to 5 million REP can be given before appreciable damage occurs. Ultraviolet irradiation causes immediate and rapid degradation of wool fiber properties independent of moisture content of the wool.

Acknowledgments

We wish to thank General Electric Corporation, Stanford Research Institute, Massachusetts Institute of Technology, and Applied Radiation Corporation for their cooperation in this study.

Literature Cited

1. Kirby, R. D., and Rutherford, H. A., TEXTILE RESEARCH JOURNAL **25**, 569 (1955).
2. McGrath, J., and Johnson, R. H., Wright Air Development Center, Technical Report 56–15 (Feb. 1956).
3. Speakman, J. B., *J. Soc. Dyers Colourists* **52**, 335 (1936).

Manuscript received January 23, 1957.

A Study of the Weathering Characteristics of Cotton Fabrics Containing Inorganic Compounds

Part II: Further Work on Copper-Chromium Treatments

G. R. F. Rose and C. H. Bayley

National Research Council, Ottawa, Canada

Abstract

A study has been made of the effect of outdoor weathering on unbleached and bleached cotton duck treated with (1) copper carbonate and chromic oxide, (2) chromic oxide aftertreated with copper naphthenate and with copper 8-hydroxyquinolinolate, and (3) chromium naphthenate mixed with copper naphthenate and copper 8-hydroxyquinolinolate respectively; and unbleached cotton sheeting treated with a mixture of copper carbonate and chromic oxide.

The treatments were applied at two levels of copper for each compound and the chromium added so as to give ratios of Cr_2O_3: CuO at, above, and below unity.

The optimum ratio of approximately 1, found in the earlier work, was confirmed for all of the above mixtures of copper and chromium.

Mixtures of copper and chromium in inorganic form seem to afford greater protection than organic mixtures or mixtures of inorganic chromium and organic copper.

Mixtures of chromic oxide and copper naphthenate were nearly as effective as the inorganic mixtures due, presumably, to the high degree of hydrolysis of the copper naphthenate. Copper 8-hydroxyquinolinolate appears to be more effective when used in conjunction with chromium naphthenate.

The presence of noncellulosic material enhances the protective effect afforded by these mixtures as does also an increase in fabric weight.

Introduction

In a recent publication [1], it was reported that unbleached cotton duck treated with mixtures of chromic oxide and copper carbonate showed, on weathering, enhanced resistance to actinic degradation as compared with the results obtained when the treatments were used separately. Moreover, the retention of copper on weathering was markedly greater with the mixed treatment than when copper carbonate was used alone. It was also noted that there seemed to be some evidence that when these compounds, in the mixed treatments, were in the molar ratio Cr_2O_3: CuO = 1, the optimum results with respect to the two above-mentioned properties were obtained. This effect was shown in the previous paper [1] in Figure 1, which is a plot of breaking strength loss versus molar ratio Cr_2O_3 : CuO for three levels of copper. In view of the fact that the number of experimental points was insufficient to give an adequately precise picture of the above relation (this being especially true in the case of the high copper treatments), it was of interest to further explore this effect. In this publication [1], the results of experiments with lightweight cellulosic fibres, viz., nainsook and saponified acetate rayon, showed that the protection afforded by these mixtures of inorganic chromium and copper is considerable, but much lower than with the unbleached duck. It was considered that this might be due either to the difference in weight of the fabrics, or to the absence of noncellulosic material in the lightweight fabrics, or a combination of these two factors. A very limited range of experiments with mixtures of inorganic copper and chromium compounds on bleached 10-oz. duck had shown that the protection was lower than with the unbleached duck, but higher than with the lightweight fabrics. It was felt that further experiments would be of interest to determine more clearly the effect of these two factors and ex-

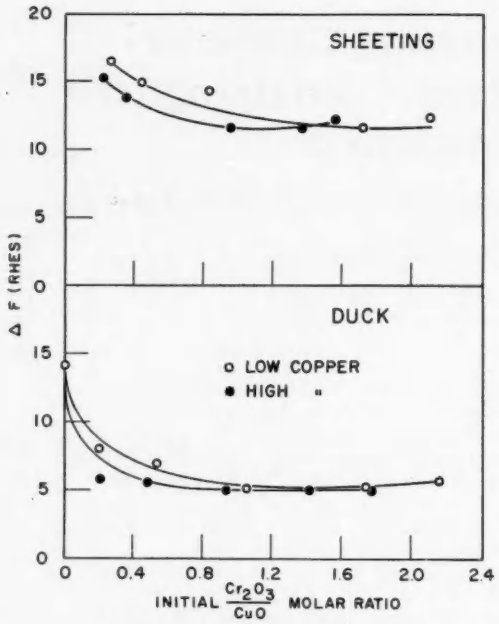


Fig. 1. Effect of ratio of Cr_2O_3 to CuO on $\triangle F$ on weathering.

periments have been carried out using unbleached duck and unbleached sheeting to examine the effect of fabric weight, and bleached and unbleached duck of the same weight to study the effect of noncellulosic materials.

It had also been shown [1] that not only were aftertreatments of organic copper on mineral-dyed duck effective, but also that unbleached duck, treated with chromic oxide, and aftertreated with copper 8-hydroxyquinolinolate (referred to hereinafter as copper-8), gave results similar to those obtained with the inorganic compounds, although the treatment appeared somewhat less effective. It was felt that an extension of this work would be of value, to determine whether mixtures of inorganic chromium and organic copper, and mixtures of organic chromium and copper would show results similar to those obtained with the mixture of inorganic copper and chromium. In the earlier work, with inorganic chromium and copper-8, no attempt had been made to determine the effect of a range of ratios Cr_2O_3 : CuO, but in planning these experiments, a range of ratios of less than 1, approximately 1, and greater than 1 was adopted in order to see whether or not the optimum ratio of 1, held also for these combinations of chromium and copper. Since it was necessary that these mixtures be compared with the mixture of the two inorganic compounds under similar exposure conditions, the earlier experiments were repeated, serving also as a check on earlier observations. To determine the effect of noncellulosic material, these treatments were carried out on 10-oz. duck, unbleached, and after being fully bleached.

Materials, Treatments, and Test Methods

The fabrics used were as follows:

Unbleached cotton duck—an unsized army duck weighing 11.7 oz./sq. yd. (10-oz. commercial designation) and having 53 3-ply warp and 43 3-ply weft yarns per inch.

Bleached duck—as above, after receiving a full commercial bleaching treatment.

Unbleached cotton sheeting—a desized sheeting weighing 3.8 oz./sq. yd. and having 57 singles warp and 59 singles weft yarns per inch.

Treatments

1. *Mixtures of inorganic compounds,* i.e., copper carbonate and chromic oxide, as well as copper carbonate alone, were applied as previously described [1].

2. *Mixtures of organic chromium and organic copper.* The chromium was in the form of chromium naphthenate, the copper compounds used being copper naphthenate and copper-8. Two levels of copper were used for each compound. The concentrations chosen were in the range ordinarily used in rotproofing work and were 0.04% copper, and 0.09% copper as copper-8, and 0.25 and 0.5% copper as copper naphthenate, on the fabric. The concentration of chromium as chromium naphthenate on the fabric was such as to give ratios of Cr_2O_3 : CuO of less than 1, 1, and more than 1 for each concentration of copper. Treating baths were prepared by dissolving, in Stoddard solvent, the appropriate amounts of chromium naphthenate and copper compound to give the desired concentrations of each on the fabric, and the samples treated in the usual way [1].

3. *Mixtures of inorganic chromium and organic copper.* The fabric was treated as described in [1] to give the desired concentration of chromic oxide on the fabric. The fabrics so treated were then given aftertreatments of copper-8 and copper naphthenate, respectively [1], so that the concentrations of chro-

TABLE I. Weather Conditions during Exposure of Samples

	1954 June 7–Oct. 6				1955 June 14–Oct. 14			
	Temp. (°F.)		Rainfall, in.	Hours of sunlight	Temp. (°F.)		Rainfall, in.	Hours of sunlight
	Max.	Min.			Max.	Min.		
June 7–June 12	75	54	0.47	57.6	June 14–June 18	82	58	0.06	58.6
" 13– " 19	75	56	0.81	43.2	" 19– " 25	76	56	0.37	35.4
" 20– " 26	79	63	1.64	45.9	" 26–July 2	84	59	0.52	66.6
" 27–July 3	73	56	0.05	39.1	July 3– " 9	88	63	0.46	78.2
July 4– " 10	71	50	0.60	68.7	" 10– " 16	85	59	0.22	65.0
" 11– " 17	75	52	0.30	58.2	" 17– " 23	90	64	0.	74.5
" 18– " 24	80	58	0.30	57.8	" 24– " 30	83	55	0.53	74.6
" 25– " 31	80	61	0.41	48.0	" 31–Aug. 6	92	65	0.75	66.4
Aug. 1–Aug. 7	76	57	0.31	46.9	Aug. 7– " 13	79	59	1.64	48.5
" 8– " 14	72	53	1.41	45.7	" 14– " 20	88	67	0.50	52.8
" 15– " 21	76	54	0.22	66.6	" 21– " 27	80	58	0.02	61.4
" 22– " 28	78	53	0.08	67.0	" 28–Sept. 3	80	51	0.37	60.1
" 29–Sept. 4	68	51	2.53	29.8	Sept. 4– " 10	74	47	0.82	60.7
Sept. 5– " 11	66	53	0.51	28.6	" 11– " 17	66	45	0.50	42.6
" 12– " 18	56	43	1.06	24.6	" 18– " 24	69	47	0.46	48.1
" 19– " 25	62	47	0.94	25.2	" 25–Oct. 1	66	44	0.41	40.2
" 26–Oct. 2	64	50	2.08	16.2	Oct. 2– " 8	62	43	1.61	27.8
Oct. 3– " 6	58	45	0.49	12.5	" 9– " 14	67	46	0.39	27.2
Average	72	54			Average	78	55		
Total			14.21	781.6	Total			9.63	988.7

mium and copper on the fabric were the same as with the mixtures of organic compounds.

Test Methods

The methods used in weathering, exposure to microbiological attack, and determination of the metal contents of the treated fabrics, are as previously given [1]. The weathering exposures were carried out at Ottawa during the summers of 1954 and 1955.

Data

The data for the weather conditions during the 1954 and 1955 exposures are given in Table I. A summary of the data for the weather conditions in 1952 and 1953, when the earlier work with chromium and copper was carried out, and in 1954 and 1955, is given in Table II.

TABLE II. Summary of Weather Conditions during Exposure of Samples

Year	Mean temp. daily, °F.		Rainfall, in.	Bright sunshine, hr.
	Max.	Min.		
1952	74	52	15.09	966
1953	74	53	11.22	955
1954	72	54	14.20	782
1955	78	55	9.63	989

The data for the effect of weathering and burial on the samples treated as described above are given in Tables III to VIII and in Figures 1 and 2.

The effect of weather conditions, for the four exposure years, as shown by the breaking strength loss and increase in fluidity of the untreated controls is as follows:

	Breaking strength loss %	ΔF, rhes
1952	51	14.2
1953	39	14.0
1954	31	11.5
1955	47	13.8

The data in Table II show that there was a decided reduction in the amount of sunlight, and a slight reduction in the rainfall in 1954 as compared with 1952. This resulted in a reduced amount of damage to the fabric. In 1955, the amount of rainfall showed a drastic reduction, but the hours of sunlight were about the same, the damage to the fabric being similar. So, while the amount of rainfall, and alternate wetting and drying of samples have a bearing on the damage, the most important factor is ap-

parently the amount of sunlight which the fabric receives.

1. *Unbleached Fabric Treated with Mixtures of Inorganic Chromium and Copper*

An examination of the data for duck and sheeting exposed in 1954, and of duck in 1955 (Table III) shows that copper carbonate alone, in the amounts used, increases the amount of chemical damage which the fiber undergoes, but that any mixture of copper carbonate and chromic oxide confers protection, reducing the strength loss, the increase in fluidity and the loss of copper. Earlier work [1] has shown that although chromic oxide alone is also effective in these respects, its effect is not so marked as with mixtures of chromic oxide and copper carbonate.

The data seem to indicate that maximum protection is achieved at a molar ratio of Cr_2O_3 : CuO of approximately unity. This is indicated more clearly in Figure 1, in which the increase in fluidity, which is a property capable of more precise measurement than breaking strength, is plotted against molar ratio of Cr_2O_3 : CuO.

In general, the protection afforded by the mixtures was somewhat greater at the higher levels of copper for the same Cr_2O_3 : CuO ratios. This effect was more marked with the duck.

In the case of the sheeting, the chromic oxide is not markedly efficacious in preventing the loss of copper on weathering, the reduction in loss being, at the most from 98 to 80%, or 18%, as compared with a reduction approximately 94 to 12%, or 82%, in the case of the duck. A similar effect has been found in the case of a 2.70 oz./sq. yd. cotton nainsook [1]. It is therefore apparent that the efficacy of chromic oxide in enhancing retention of the copper on weathering is influenced by the weight of the fabric. But even with the lighter weight fabric, the degree of protection afforded by the treatment is surprising in view of the low residual copper content after weathering. Thus, for example, a residual content of 0.01% copper oxide combined with 0.40% chromic oxide reduces the breaking strength loss from 37% for copper alone to 18%. That the weight of the fabric influences the retention of copper is also shown in some tests with 8-, 10- and 12-oz. unbleached duck, of similar construction, treated with the mixture of inorganic copper and chromium and exposed in the summer of 1954. These samples (Table VII) showed a loss of copper of 51, 42, and 38%, respectively, with the same initial concentration of copper, and approximately the same Cr_2O_3 : CuO ratio (viz., 0.32–0.40).

It therefore appears that the effect of these treatments is reproducible, and that the damage is controlled to about the same extent, regardless of differences in weather conditions during exposure. Greater rainfall causes an increase in the loss of copper but a very low residual copper combined with the chromic oxide, ensures excellent protection to the fabric against accompanying microbiological attack on weathering, see Table IV.

2. *Comparison of the Efficacy of Mixtures of Inorganic Copper and Chromium, Inorganic Chromium and Organic Copper, and Organic Copper and Chromium Compounds*

Unbleached fabric. The effect on the fabric, of weathering in the presence of the three copper compounds used alone, varies. Copper-8 protects the fabric, copper naphthenate apparently has no effect, and copper carbonate accelerates breakdown to a marked degree. But the mixture of any of these copper compounds with chromium brings about a marked increase in protection to the fabric on weathering. This is seen in the reduced strength loss, and lowered increase in fluidity, and in the increased retention of copper. This effect is shown in the last three columns of Tables IV, V, and VI. Of the three combinations (see Tables IV, V, and VI), the mixtures of inorganic copper and chromic oxide are the most effective. Of the other two combinations, copper naphthenate is much more effective combined with chromic oxide than with chromium naphthenate, and although, with copper-8, the form of the chromium seems to be of less importance, there is some indication that it is more effective with chromium naphthenate. Copper naphthenate with chromic oxide is about as effective as the mixture of copper carbonate with chromic oxide, and this is probably due to the fact that copper naphthenate is hydrolyzed to inorganic copper to the extent, at these concentrations, of approximately 35–50% [2]. Thus, the performance of this combination approaches that of the mixture of inorganic compounds. So, in weathering, the relative efficacy of the mixtures of straight organic, and of organic plus inorganic compounds, will depend on the copper compound. If the copper compound is readily hydrolyzed, the mixture

with inorganic chromium will probably be more effective; if it is not, the mixture with organic chromium probably will give more protection.

It may be noted that, regardless of the effect of the copper compound by itself, the addition of chromium brings all combinations to approximately the same level of protection against actinic breakdown. (See ΔF on weathering, Tables IV, V, & VI.) Thus, the degree of improvement brought about by the chromium in the case of copper carbonate is very much greater than with copper-8, since the former accelerates damage to a marked degree, whereas the latter by itself gives excellent protection. It seems unlikely that protection against actinic breakdown afforded by these mixtures of copper and chromium compounds can be the result of increased retention of copper in its original form, because chromium with copper carbonate gives the greatest protection, and yet copper carbonate alone has the most damaging effect. It is more likely that these mixtures of copper

TABLE III. Protective Effects of Copper Used Separately and in Mixtures with Chromium

Fabric	General level oxide content		Initial oxide content, %		Copper oxide content after weathering, %	Ratio $\frac{Cr_2O_3}{CuO}$		Breaking strength loss, %	ΔF, rhes	Loss of copper, %
	CuO	Cr_2O_3	CuO	Cr_2O_3		Initial	After weathering			
Unbleached 10-oz. cotton duck (1954)	—	—	—	—	—	—	—	31	11.5	—
	medium	—	0.68	—	—	—	—	38	—	—
	high	—	1.30	—	0.081	—	—	40	14.1	94
	medium	low	0.55	0.21	0.155	0.20	0.71	21	8.0	73
	"	medium	0.42	0.43	0.153	0.54	1.44	18	7.1	64
	low	"	0.36	0.72	0.168	1.05	1.93	17	5.1	53
	"	high	0.36	1.20	0.281	1.74	2.12	17	5.2	22
	"	"	0.33	1.36	0.26	2.16	2.69	16	5.7	21
	high	low	0.96	0.38	0.35	0.21	0.48	17	5.8	64
	"	medium	0.90	0.80	0.421	0.47	0.94	16	5.4	53
	"	high	0.83	1.49	0.66	0.94	1.13	13	5.1	20
	"	"	0.78	2.12	0.56	1.42	1.68	13	4.9	28
	"	"	0.73	2.46	0.54	1.76	1.49	14	5.1	26
Unbleached 10-oz. cotton duck (1955)	—	—	—	—	—	—	—	47	13.8	—
	medium	—	0.50	—	0.061	—	—	56	20.7	88
	high	—	0.74	—	0.093	—	—	56	21.4	87
	medium	low	0.49	0.33	0.29	0.35	0.59	18	8.2	41
	"	medium	0.44	0.70	0.32	0.83	1.11	13	6.6	27
	"	high	0.47	1.56	0.42	1.74	1.92	8	5.3	11
	high	medium	0.82	0.98	0.68	0.63	0.66	12	6.0	17
	"	high	0.93	2.12	0.84	1.19	1.30	12	5.4	10
	"	"	0.85	2.60	0.78	1.59	1.72	8	7.3	8
Desized unbleached cotton sheeting (1954)	—	—	—	—	—	—	—	33	17.2	—
	medium	—	0.56	—	0.013	—	—	37	—	98
	high	—	1.34	—	0.016	—	—	37	—	99
	medium	low	0.67	0.33	0.011	0.26	—	21	16.4	98
	"	medium	0.52	0.44	0.013	0.44	—	18	14.9	97
	low	"	0.44	0.70	0.035	0.83	—	16	14.2	92
	"	high	0.36	1.18	0.036	1.71	—	20	11.6	90
	"	"	0.37	1.49	0.061	2.10	—	20	12.2	83
	high	medium	1.31	0.55	0.01	0.22	—	21	15.2	99
	"	"	0.99	0.67	0.034	0.35	—	20	13.7	97
	"	high	0.78	1.42	0.114	0.95	—	18	11.6	85
	"	"	0.71	1.86	0.124	1.37	—	18	11.6	83
	"	"	0.70	2.08	0.145	1.55	—	16	12.2	79

and chromium compounds are converted into a copper compound which is protective in character and that the concentration and resultant efficacy of this protective compound depends on the retention of copper.

It may be noted that, whereas the loss of copper is approximately the same for each copper compound used alone, with copper-8 the retention of copper in the presence of chromium is much lower than with the other two compounds. This may be due to the very low concentrations of chromium used. These concentrations are such as to give the same ratios of Cr_2O_3 : CuO as with the other compounds but because of the low concentrations of copper as copper-8, the absolute amount of chromium in the chromium-copper-8 mixtures is much lower than with the other two compounds. Although these small amounts of chromium are sufficiently high to ensure excellent protection against actinic breakdown, they are not high enough to retain copper to any marked extent, and consequently the resistance of copper-8 with chromium to microbiological attack on weathering is much lower than with the other compounds. The data in Table VIII show that with the same concentration of copper as copper-8, but with a much higher content of chromic oxide, the loss of copper is reduced from 74 to 45%. These tests were carried out in different years (1953 and 1955), but an examination of the weather data in Table II shows that weather conditions were similar, and it will also be noted that the damage to the untreated controls was very similar (Table VIII).

3. *Effect of Noncellulosic Material on These Treatments*

Since the fabrics are identical in other respects, a comparison of the effects, on weathering, of these treatments on unbleached and bleached duck will indicate the effect of noncellulosic material. Noncellulosic material protects the untreated fabric to a very marked extent against actinic breakdown but increases breaking strength loss on weathering slightly, due undoubtedly to microbiological attack, since unlike the bleached sample, the unbleached sample always shows abundant mildew. (See data for untreated fabric in Tables IV, V, and VI.) With each of the copper compounds used alone, noncellulosic material brought about a somewhat greater retention of the copper on weathering, resulting in greater resistance to microbiological attack. The protection afforded by noncellulosic material against the damaging effect on the sample of copper carbonate is only very slight. But the great improvement brought about by mixtures of copper carbonate and chromic oxide is increased by the noncellulosic material. Copper naphthenate, used alone, accelerates to a slight extent the damage in weathering, but the protection afforded by the noncellulosic constituents compensates for this. The improvement brought about by the addition of chromium to copper naphthenate is enhanced to a very considerable extent by the presence of noncellulosic material when the chromium is in inorganic form, but it has less effect when the chromium is in organic form. The noncellulosic material improves the effect of copper-8, alone or combined with chromium, to only a slight extent.

For the copper compounds tested, the relative values of the various copper and chromium mixtures are the same with bleached as with unbleached fabric. The noncellulosic material tends to improve, in varying degrees, the effect of these mixtures, by causing an increased retention of copper, and in reducing actinic breakdown and the general damaging effect of weathering (see Figure 2).

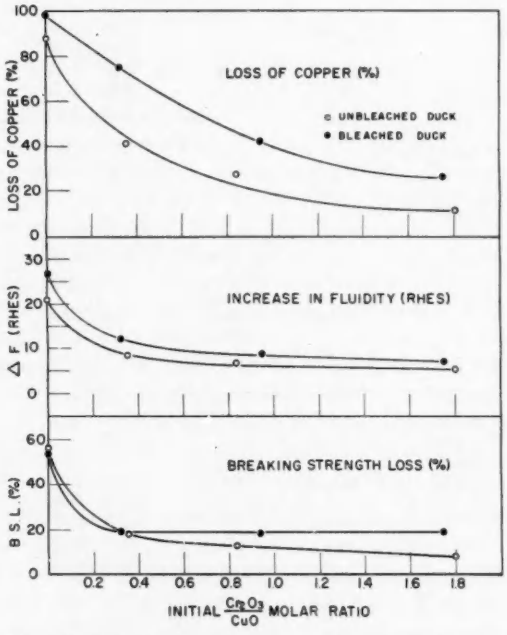


Fig. 2. Protective effect on weathering of noncellulosic material in fabric treated with mixtures of inorganic copper and chromium.

TABLE IV. Data on Mixtures of Inorganic Chromium and Copper Compounds

Fabric	Treatment	Initial oxide content, %		Copper oxide content after weathering, %	Ratio $\frac{Cr_2O_3}{CuO}$		Effect of weathering: Breaking strength loss, %			Effect of weathering				
												% Decrease due to chromium		
		CuO	Cr_2O_3	CuO	Initial	After weathering	Leached and buried 2 wk.	Weathered	Weathered and buried 2 wk.	ΔF, rhes	Loss of copper, %	Breaking strength loss, %	Loss of copper, %	Difference in ΔF due to chromium, rhes
Unbleached 10-oz. duck (1955)	none	—	—	—	—	—	100	47	—	13.8	—	—	—	—
	Copper carbonate	0.50	—	0.061	—	—	4	56	59	20.7	88	—	—	—
		0.74	—	0.093	—	—	0	56	61	21.4	87	—	—	—
	Cr_2O_3 and Copper carbonate	0.49	0.33	0.29	0.35	0.59	7	18	23	8.2	41	68	53	12.5
		0.44	0.70	0.32	0.83	1.11	29	13	14	6.6	27	77	70	14.1
		0.47	1.56	0.42	1.74	1.92	44	8	14	5.3	11	86	88	15.4
		0.82	0.98	0.68	0.63	0.66	14	12	14	6.0	17	79	80	15.4
		0.93	2.12	0.84	1.19	1.30	20	12	14	5.4	10	79	89	16.0
		0.85	2.60	0.78	1.59	1.72	37	8	20	6.2	8	86	90	15.2
Bleached 10-oz. duck (1955)	none	—	—	—	—	—	100	41	—	19.0	—	—	—	—
	Copper carbonate	0.33	—	0.003	—	—	3	54	74	27.4	99	—	—	—
		0.66	—	0.015	—	—	3	54	74	26.6	98	—	—	—
	Cr_2O_3 and Copper carbonate	0.47	0.29	0.11	0.32	1.33	38	19	25	11.8	77	65	22	15.6
		0.43	0.77	0.25	0.94	1.34	43	19	21	8.7	42	65	57	18.7
		0.42	1.41	0.31	1.75	2.14	54	19	31	7.1	26	65	74	20.3
		0.84	0.93	0.51	0.58	0.84	18	19	22	7.2	40	65	59	19.4
		0.89	2.12	0.77	1.24	1.35	55	19	33	5.9	13	65	87	20.7
		0.94	2.82	0.86	1.57	1.71	60	19	18	6.8	9	65	91	19.8

TABLE V. Data on Combinations of Inorganic Chromium and Organic Copper Compounds

Fabric	Treatment	Initial metal content, %		Copper content after weathering, %	Ratio $\frac{Cr_2O_3}{CuO}$		Breaking strength loss, %			Effect of weathering				
												% Decrease due to chromium		
		Copper	Cr_2O_3	Copper	Initial	After weathering	Leached and buried 2 wk.	Weathered	Weathered and buried 2 wk.	ΔF, rhes	Loss of copper, %	Breaking strength loss, %	Loss of copper, %	Difference in ΔF due to chromium, rhes
Unbleached 10-oz. duck (1955)	none	—	—	—	—	—	100	47	—	13.8	—	—	—	—
	Copper-8	0.04	—	0.006	—	—	3	36	59	9.7	85	—	—	—
		0.09	—	0.023	—	—	3	30	36	7.2	75	—	—	—
	Cr_2O_3 and Copper-8	0.039	0.053	0.0086	0.56	3.53	8	27	60	8.5	78	25	8	1.2
		0.044	0.14	0.011	1.33	6.18	8	27	43	7.2	75	25	12	2.5
		0.05	0.24	0.013	2.01	9.66	8	27	43	7.6	74	25	13	2.1
		0.07	0.14	0.022	0.83	3.33	8	27	36	6.5	69	10	8	0.7
		0.081	0.28	0.026	1.45	5.63	8	27	36	6.9	68	10	9	0.3
		0.089	0.38	0.032	1.79	5.56	8	27	27	6.1	64	10	15	1.1
Bleached 10-oz. duck (1955)	none	—	—	—	—	—	100	41	—	19.0	—	—	—	—
	Copper-8	0.04	—	0.0007	—	—	4	33	51	13.9	98	—	—	—
		0.096	—	0.0022	—	—	4	33	51	13.6	98	—	—	—
	Cr_2O_3 and Copper-8	0.044	0.077	0.0032	0.73	11.60	4	28	70	12.0	93	15	5	1.9
		0.048	0.117	0.0045	1.02	11.27	4	28	54	11.5	91	15	7	2.4
		0.048	0.21	0.0024	1.83	39.22	4	28	54	11.8	95	15	3	2.1
		0.082	0.13	0.0053	0.66	8.78	4	28	50	12.7	94	15	4	0.9
		0.082	0.21	0.0055	1.06	16.16	4	28	67	12.4	93	15	5	1.2
		0.076	0.28	0.0054	1.54	20.34	4	28	64	13.0	93	15	5	0.6
Unbleached 10-oz. duck (1955)	none	—	—	—	—	—	100	47	—	13.8	—	—	—	—
	Copper naphthenate	0.26	—	0.061	—	—	59	41	44	13.5	77	—	—	—
		0.51	—	0.27	—	—	46	47	47	13.9	47	—	—	—
	Cr_2O_3 and Copper naphthenate	0.26	0.25	0.20	0.40	0.63	4	21	28	9.8	23	49	70	3.7
		0.27	0.52	0.22	0.80	1.26	4	21	23	8.6	19	49	75	4.9
		0.26	1.14	0.25	1.83	2.38	4	21	23	8.5	4	49	95	5.0
		0.63	0.66	0.52	0.44	0.65	4	21	19	7.3	17	55	64	6.6
		0.66	1.32	0.56	0.84	1.21	4	21	21	7.0	15	55	68	6.9
		0.66	2.05	0.62	1.30	1.70	4	21	21	8.0	6	55	87	5.9
Bleached 10-oz. duck (1955)	none	—	—	—	—	—	100	41	—	19.0	—	—	—	—
	Copper naphthenate	0.26	—	0.0048	—	—	27	57	66	19.5	98	—	—	—
		0.51	—	0.20	—	—	5	57	53	20.9	61	—	—	—
	Cr_2O_3 and Copper naphthenate	0.25	0.26	0.047	0.44	1.78	3	41	42	14.1	81	28	17	5.4
		0.26	0.41	0.084	0.66	2.37	3	37	36	13.2	68	35	31	6.3
		0.26	0.93	0.145	1.50	3.32	3	29	30	11.3	44	49	55	8.2
		0.53	0.69	0.38	0.54	0.55	3	32	39	12.0	30	44	51	8.9
		0.50	0.91	0.37	0.76	1.24	3	32	32	10.1	26	44	57	10.8
		0.51	2.24	0.45	1.83	2.61	3	27	32	8.7	12	53	80	12.2

TABLE VI. Data on Mixtures of Chromium and Copper Organic Compounds

Fabric	Treatment	Initial metal content, %		Copper content after weathering, %	Ratio $\frac{Cr_2O_3}{CuO}$		Breaking strength loss, %			Effect of weathering				
												% Decrease due to chromium		
		Copper	Cr_2O_3	Copper	Initial	After weathering	Leached and buried 2 wk.	Weathered	Weathered and buried 2 wk.	ΔF, rhes	Loss of copper, %	Breaking strength loss, %	Loss of copper, %	Difference in ΔF due to chromium, rhes
Unbleached 10-oz. duck (1955)	none	—	—	—	—	—	100	47	—	13.8	—	—	—	—
	Copper-8	0.04	—	0.006	—	—	3	36	59	9.7	85	—	—	—
		0.09	—	0.023	—	—	3	30	36	7.2	75	—	—	—
	Chromium naphthenate and Copper-8	0.034	0.048	0.0025	0.59	8.78	9	27	70	8.3	93	25	0	1.4
		0.032	0.08	0.012	1.04	3.44	9	27	67	8.2	65	25	24	1.5
		0.033	0.15	0.017	1.91	4.92	9	20	67	7.0	48	44	44	2.7
		0.078	0.11	0.027	0.59	1.94	3	24	45	10.2	65	20	13	—
		0.079	0.21	0.039	1.11	2.95	3	17	58	6.6	51	43	32	0.6
		0.085	0.33	0.044	1.63	3.68	3	17	36	6.1	48	43	36	1.1
Bleached 10-oz. duck (1955)	none	—	—	—	—	—	100	41	—	19.0	—	—	—	—
	Copper-8	0.04	—	0.0007	—	—	4	33	51	13.9	98	—	—	—
		0.096	—	0.0022	—	—	4	33	51	13.6	98	—	—	—
	Chromium naphthenate and Copper-8	0.031	0.044	0.0031	0.59	7.42	5	23	50	10.7	90	30	8	3.2
		0.036	0.10	0.0043	1.16	9.97	5	23	53	10.9	88	30	10	3.0
		0.033	0.16	0.0055	2.03	14.26	5	23	53	10.1	83	30	15	3.8
		0.085	0.11	0.016	0.54	3.59	5	23	44	10.7	81	30	17	2.9
		0.083	0.21	0.032	1.06	3.76	5	23	47	9.4	61	30	38	4.2
		0.083	0.33	0.04	1.66	4.57	0	23	41	9.6	52	30	47	4.0
Unbleached 10-oz. duck (1955)	none	—	—	—	—	—	100	47	—	13.8	—	—	—	—
	Copper naphthenate	0.26	—	0.061	—	—	59	41	44	13.5	77	—	—	—
		0.51	—	0.27	—	—	46	47	47	13.9	47	—	—	—
	Chromium naphthenate and Copper naphthenate	0.22	0.25	—	0.48	—	33	28	49	9.4	—	32	—	4.3
		0.26	0.69	0.16	1.11	2.25	33	21	49	8.8	38	49	51	4.7
		0.23	1.03	0.15	1.85	3.38	38	21	46	8.6	35	49	55	4.9
		0.46	0.68	0.34	0.62	1.06	50	28	29	10.7	26	40	45	3.2
		0.49	1.21	0.32	1.03	1.91	46	21	27	9.2	35	55	25	4.7
		0.49	1.91	0.31	1.63	3.05	37	21	27	8.6	37	55	21	5.0
Bleached 10-oz. duck (1955)	none	—	—	—	—	—	100	41	—	19.0	—	—	—	—
	Copper naphthenate	0.26	—	0.0048	—	—	27	57	66	19.5	98	—	—	—
		0.51	—	0.20	—	—	5	57	53	20.9	61	—	—	—
	Chromium naphthenate and Copper naphthenate	0.19	0.27	0.12	0.59	1.20	6	29	43	18.3	37	49	62	1.2
		0.23	0.58	0.17	1.06	1.78	16	29	35	17.4	26	49	73	2.1
		0.23	0.98	0.17	1.77	2.95	12	23	35	15.5	26	60	73	4.0
		0.49	0.64	0.38	0.55	0.91	19	29	35	18.4	22	49	64	2.5
		0.48	1.25	0.26	1.09	1.73	26	29	43	17.2	46	49	25	3.7
		0.47	1.62	0.30	1.44	2.81	22	27	29	17.5	37	53	39	3.4

TABLE VII. Effect of Weight of Fabric on Resistance to Weathering of Samples Treated with $CuCO_3$ and Cr_2O_3 (1954)

Fabric	CuO, %	Ratio $\frac{Cr_2O_3}{CuO}$	On weathering: Breaking strength loss, %	On weathering: ΔF, rhes	On weathering: Loss of copper, %
8-oz. unbleached	—	—	28	11.8	—
cotton duck	0.51	0.38	16	7.4	51
10-oz. unbleached	—	—	26	10.0	—
cotton duck	0.50	0.40	14	7.0	42
12-oz. unbleached	—	—	28	9.6	—
cotton duck	0.48	0.32	14	3.7	38

TABLE VIII. Effect of the Amount of Chromium on the Protection Afforded by a Mixture of Copper-8 and Chromic Oxide

Fabric	Year	Copper, %	Cr_2O_3, %	On weathering: Breaking strength loss, %	On weathering: ΔF, rhes	On weathering: Loss of copper, %
Unbleached 10-oz. duck	1953	0.052	0.92	18	6.6	46
		0.053	1.36	15	7.7	45
		0.04		28	8.1	87
Untreated control				39	14.0	
Unbleached 10-oz. duck	1955	0.05	0.24	28	7.2	74
		0.04		36	9.7	85
Untreated control				47	13.8	

In general, the optimum ratio Cr_2O_3 : CuO of approximately 1, found with the mixture of inorganic compounds, applies also to the mixtures of inorganic chromium and organic copper, and the mixtures of organic copper and chromium compounds. In a few cases, chiefly with bleached fabric, the chromium at even the highest concentration used failed to prevent the loss of copper, which was so high that any effect of a critical range in the original ratios Cr_2O_3 : CuO was lost.

A comparison of the results on exposure of unbleached fabric of two contrasting weights, viz., 10-oz. duck and sheeting (Table III) with the results of the same unbleached duck and bleached duck of the same weight (Table IV) treated similarly with these inorganic copper-chromium mixtures, indicates that for these particular treatments and for these particular weights of fabric a decrease in the weight of the fabric causes a greater decrease in protection than the absence of noncellulosic material.

Acknowledgment

The authors wish to acknowledge with thanks the assistance given by Miss E. Fraser and Miss D. Laird of this laboratory and by Mr. F. W. Baker, Meteorological Observer, Central Experimental Farm, Department of Agriculture, Ottawa, for providing the weather data; thanks also to the Defense Research Board, Department of National Defense, Ottawa, for financial assistance in this work.

Literature Cited

1. Rose, G. R. F. and Bayley, C. H., TEXTILE RESEARCH JOURNAL **24**, 792–802 (1954).
2. Rose, G. R. F. and Bayley, C. H., unpublished work.

Manuscript received December 19, 1956.

INDUSTRIAL SECTION

Recent Progress in Polyamide and Polyester Fibers[1]

G. M. Richardson, H. E. Stanley, and W. W. Heckert

Textile Fibers Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

THE principal commercial polyamide and polyester fibers are made from three polymers, the two nylons from polyhexamethylene adipamide (known as 66 nylon) and polycaproamide (known as 6 nylon), and the polyester fibers from polyethylene terephthalate. All three of these polymers stem from the classical researches of Wallace Carothers and his associates. The two nylons were synthesized and evaluated in the original survey which led to the commercialization of 66 nylon by Du Pont in 1939. Polyethylene terephthalate was first synthesized by Whinfield and Dickson. Dacron[2] polyester fiber, manufactured by Du Pont, and Terylene[3] polyester fiber, manufactured by I.C.I., are based on this polymer.

Since most of the recent progress with these fibers has come within the domain of application-research, this discussion will be limited to advances of this type. Furthermore, the subject will be treated in an illustrative rather than an exhaustive manner.

The nylons and polyester fibers of today excelled in strength, toughness, abrasion resistance, elasticity, crease resistance, and what later came to be called ease of care properties. Initially, at least, they failed to excel in aesthetic properties. Their fabrics were often deficient in hand, drape, texture, coloration, etc. This proved to be a great handicap, for in many textile uses it is precisely these properties which control the volume of sales. Consequently, the objective of countless textile investigations has been to improve the aesthetics of fabrics made from these fibers. These are queer problems to assign to chemists and engineers, yet many of the conspicuous advances have been made by just such personnel.

First let us consider some of the procedures which have been uncovered for improving the texture, from continuous filament yarns. We shall touch upon them only briefly to show their relationship to other researches aimed at improving the aesthetics of fabrics made from nylon and polyester fibers.

The synthetic fiber industry got its start with continuous filament yarns, such as artificial silk. Such yarns are used extensively in women's hosiery where their lack of bulk and covering power is considered a virtue. They are used in lingerie and in dresswear of the dressy types, in sheers, failles, and taffetas. For many years continuous filament yarns were the mainstay of the business. However, in many areas they are now under competitive pressure from the staple fibers, both natural and synthetic. There has been a strong trend in recent years to casual wear. In such garments the texture, the fuzzy, uneven, dull surface, and the bulk and covering power of staple fiber fabrics are preferred over the more lustrous silky appearance and feel of fabrics made of continuous filament yarns.

[1] Presented at the Conference on Man Made Fiber Progress at the New York Academy of Sciences, October 12, 1956. This article appeared in the *Annals of the New York Academy of Sciences* **67**, 11 (May 24, 1957).

[2] Dacron is Du Pont's registered trademark for its polyester fiber.

[3] Terylene is I.C.I.'s registered trademark for its polyester fiber.

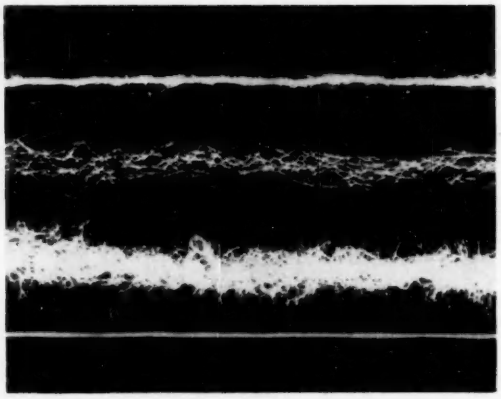


Fig. 1. Types of textured yarns (top to bottom). Taslan, Ban-Lon, Helanca, filament.

Of course, one solution to this problem is to chop the filament yarn into staple fiber and then spin it back into yarn, but to the scientist this solution is admission of defeat. Attempts to find a better solution have given rise to a whole group of textured yarns which are known in this country by their trademarks, Agilon, Ban-Lon, Burmilized, Flufflon, Helanca, Tycora, and Taslan.[4]

In all of these products the change in texture and the increase in bulk and cover are caused by a permanent crimp, curl, or loops formed in the filaments. This is illustrated in Figure 1. The first five of these processes comprise a step in which a crimp or curl is imparted to the filaments, followed by one in which this crimp or curl is permanently set in the fiber with heat. They produce yarns which have a high degree of elasticity compared with the untreated filament yarns. In the case of Helanca yarns, high twist is employed to curl the filaments; the twist is later removed after heat setting. Ban-Lon yarns are crimped by continuously stuffing them into an enclosure and then allowing them to escape. In all cases the crimp or curl is set in the filament by a heat treatment. This step induces further perfection of the crystalline areas in the fiber, forming new bonds between the molecules making up the fiber; these bonds fix the crimp. Fibers which are incapable of taking a permanent set do not respond to these processes.

When Helanca nylon yarns were first made, it was observed that if they were stretched out to their full linear length, the forces tending to restore the filaments to their crimped or curled form were of sufficient magnitude to give the yarns very remarkable elasticity. This gave us the first stretch hose. Thus a by-product property became of more importance than the original objective.

Ban-Lon yarns show intermediate elasticity and a substantial increase in cover. They are finding use in many types of knitwear, such as sweaters.

Taslan textured yarns, invented by A. L. Breen of the Du Pont Pioneering Research Laboratory, do not rely upon a setting step to fix the bulk or texture. They are made up of single filament loops, randomly spaced and interlocked by frictional forces. They show no more elasticity than untextured yarn. To make them, continuous filament yarn is fed through an air jet at a faster rate than it is drawn off by take-up rolls located on the far side of the jet. Though the resulting yarns are only 10–20% shorter in length after texturing, their increase in volume normally amounts to 50–200%. The covering power of fabrics may be increased by 75–100% over that of control fabrics. Fabrics of Taslan have a dry, rather crisp hand. Their frictional coefficients are often threefold those of control fabrics. This may turn out to be one of the most useful properties of Taslan textured yarns.

A most promising new product is a shirt made from Taslan. It has been introduced to the trade by the Matson Shirt Company and is made from a Burlington fabric of Taslan textured Dacron yarn. It has good appearance, a pleasing hand, is comfortable, and soils much less quickly than an ordinary filament shirt because it makes much less contact with the skin. It has good wash and wear properties. This oxford-weave shirt was washed and dried in a Whirlpool automatic washer and clothes dryer and is now being worn without ironing.

Fabric Finishing

Up to this point a variety of procedures have been considered for changing fabric properties by treatments applied to yarns. These are recent innovations. A more orthodox way to improve the aes-

[4] Registered trademarks used to designate textured yarns made in accordance with quality standards set by Deering Milliken & Co., Inc.; Joseph T. Bancroft & Sons, Inc.; Burlington Industries, Inc.; Marionette Mills, Inc.; Heberlein & Co.; Textured Yarns Co., Philadelphia; and E. I. du Pont de Nemours & Co., Inc. respectively.

thetics of fabrics has been to apply physical or chemical treatments to the fabric itself.

In the case of natural fibers and rayon, fabric finishing usually starts with a boil-off or scour in soap and water. Recent studies on the finishing of synthetic fiber fabrics not only have produced some very attractive fabrics, but also are shedding new light on the importance of this first step in the finishing of fabrics of natural fiber. It now appears that swelling and working of the yarns in a cotton or rayon fabric during the scouring step causes them to shift their position so as to achieve a much more uniform distribution of the yarns in the fabric than ordinarily results from the weaving process alone. This minimizes what would otherwise show up as "reediness" or streaks in the fabric. Such streaks have the superficial appearance of dyeing nonuniformities, but are actually caused by the irregular configuration of the yarns rather than by variations in dye content. When, however, fabrics of polyamide or polyester fibers are scoured in soap and water, no analogous swelling takes place and one might therefore expect that it would often be difficult to avoid reediness or the appearance of dye streaks. This is actually the case.

A recent invention not only lends plausibility to this analysis but also goes a long way toward solving the difficulty. It achieves what appears to be a more uniform dyeing of nylon fabrics by carrying out the dyeing in the presence of a phenolic swelling agent under relaxed conditions. Some of the most uniformly dyed nylon fabrics ever seen were prepared in this manner. F. Schulze of the Du Pont Textile Research Laboratory has obtained evidence that swelling of the nylon yarns in this manner causes them to redistribute themselves more uniformly in the fabric. Thus benefits analogous to those accomplished with a relaxed scour of cotton or rayon fabrics are accomplished with nylon. This invention, which was purchased by Du Pont, is the subject of a pending patent application and the process has been made available to all dyers of nylon fabrics.

Many cellulosic fabrics are finished subsequent to dyeing by impregnating them with urea-formaldehyde or other analogous resin-forming ingredients which are capable of reacting with the cellulose. After drying, the fabric is heated for a short period of time, during which the resin polymerizes and reacts with the cellulose to form cross-links between the cellulose molecules. These cross-links stabilize the fabric in whatever form it existed during the polymerizing step. Surface effects, such as embossed impressions, are fixed for the life of cross links. The fabric improves in crease resistance and feels as though it had more substance.

The unique thing about polyamide and polyester fibers is that they respond to heat alone to take on a permanent set, much as do cellulosic fibers impregnated with a methylol urea. They become dimensionally stable. Embossed patterns are fixed permanently. Properly constructed fabrics improve in liveliness and crease resistance. They do not lose appreciably in strength or abrasion resistance. This gives polyamide and polyester fabrics a versatility which remains to this day only partly exploited.

Heat setting was first used in the preboarding step in the manufacture of nylon hose to fix the stockings in a nonwrinkled state so that they could be dyed without inserting permanent wrinkles. Later a preboarding step was used to shape seamless hose to the desired dimensions. This capacity of nylon for being shaped during preboarding made possible the rise of the seamless industry to its present position of importance. Dimensional stability imparted to nylon tricot by a heat-setting step is responsible for the manifold uses for nylon tricot. Setting with dry heat, a little below the melting point, has long been known to improve greatly the hand and wrinkle resistance of woven fabrics of nylon. However, only recently has any use been made of heat setting to modify what might be called the fine-grained structure of nylon fabrics. For example, it is possible to calender nylon tricot fabrics under conditions of high temperature and pressure to achieve a marked change in the feel of the fabric, an increase in covering power, and a reduction in the thickness of the fabric. This is illustrated in Table I.

TABLE I. Calendering of Nylon Tricot

	Uncalendered	Calendered
Weight of fabric, oz./yd.^{2}	2.7	3.29
Thickness, mils	0.0120	0.0105
Covering power		
Light transmission, %	6.7	2.6

Note in particular that the light transmission of the calendered tricot fabric has been reduced to 2.6%. This compares with 6.7% for the uncalendered tricot and 2.5% for a cotton slip fabric which was deemed

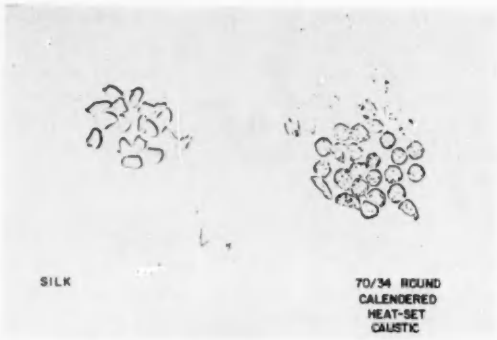


Fig. 2. Cross sections after caustic finishing.

to have good covering power. If the fabric is properly heat set, these changes are permanent to washing. Another fabric is an embossed nylon tricot, which is produced by Munsingwear and called "Intaglio," in which the pattern has been fixed by heat setting. In this manner it is possible to prepare a whole series of fabrics varying widely in appearance and hand from each polyamide or polyester fabric. It would appear that there must be many unexploited opportunities in this field.

Dacron polyester fiber possesses another very unusual property which offers further versatility in finishing. When the fiber is exposed to strongly alkaline media, surface polymer saponifies and dissolves, but the fiber which remains retains most of its strength unimpaired! When a tightly constructed woven fabric of Dacron polyester fiber is subjected to boiling in 3% sodium hydroxide for about 90 min., the weight loss might amount to about 15%, and the fabric would then feel much softer, livelier, and generally more attractive. To a certain extent this improvement in fabric aesthetics is analogous to that which occurs when silk fabrics are degummed, thereby losing approximately 25% of their weight and becoming more open in construction.

Studies by Navin Gajjar of the Du Pont Textile Research Laboratory have shown that a combination of calendering, heat setting under relaxed conditions, and caustic treating imparts a particularly attractive hand to some fabrics of Dacron polyester fiber.

This is what we think happens in each step:

1. In calendering there is actual deformation of fiber cross sections to make them more like silk. After calendering, the fabric is parchmentlike.

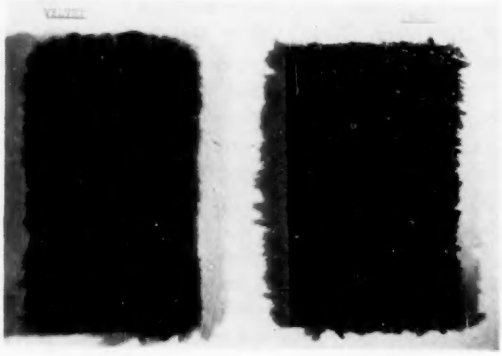
2. During relaxed heat setting, the fabric shrinks; the amplitude of weave crimp is increased and is permanently set.

3. The caustic treatment serves two purposes. First, it hydrolyzes away the outer layers of the fibers. This creates enough free space to permit the weave crimp to act as a multitude of springs; hence, the fabric becomes livelier. Second, the caustic hydrolysis of the calendered yarns actually accentuates the deformation of cross section produced in calendering and produces final cross sections (illustrated in Figure 2) reminiscent of silk.

Caustic finishing of polyethylene terephthalate fabrics was first disclosed by John D. H. Hall in U.S. Patent No. 2590402. Insofar as the process described is dominated by this patent it may be practiced by the public through an agreement between Du Pont and Imperial Chemical Industries, who own the patent.

Rugs

An end use for nylon, where recent advances in aesthetics are paving the way for a success which could not be won with functional properties alone, is the 100% nylon rug. Such rugs have been in existence for at least nine years. For a long time their durability has been known to be phenomenal. Witness the department store in Nashville, Tenn. which as a stunt placed a 100% nylon rug on one of the principal highways to test its durability. Truck drivers passing over the rug soon entered into the spirit of the test and applied their brakes as they



Velvet Twist

Fig. 3. Nylon carpets.

crossed the rug. After it had been crossed by 22,000 automobiles, trucks, and busses the rug was cleaned and examined by store officials, who decided it looked substantially as good as new and quite salable. Yet nylon rugs have not sold in the volume they might. Covering power needed improvement both as a route to superior aesthetics and as a route to lower costs. Rugs with uncut pile often pilled objectionally during service. There have been difficulties in styling a full line of nylon rugs. All of these are typical aesthetic problems and solutions to them are well along.

Initial studies disclosed that the covering power of nylon rug yarns increased as the filament denier of the filaments was decreased, but unfortunately resistance to matting, a most important property, fell off with decrease in filament denier. Clearly a compromise had to be made. A filament denier of 15 was chosen as optimum for round filaments. Since that time we have varied the shape of cross section and it has been discovered that filaments with an irregular cross section have up to 25% more covering power than round filaments of the same denier. Normal crush resistance and durability are retained. Staple of this type is now being offered in experimental quantities.

In the meantime, a major improvement in the aesthetics of nubby and frieze rugs was made possible by twist-setting studies conducted by Du Pont technical groups. A similar development with 6 nylon was made by the Industrial Rayon Corporation. In Figure 3 the velvet sample is a rug, tufted with untwist-set, all nylon yarn. Note the objectionable appearance of rows of nylon threads in this sample. Even though the individual tufts have to a considerable extent lost their identity, the rows of yarn stand out clearly, giving the rug a lean appearance. The other sample marked "twist" was prepared from a nylon rug yarn in which the twist had been well set by exposure to live steam. The twist and kinks in these tufts are permanently set and persist through wear and even through rotary brushing during cleaning.

To achieve such durable setting, it was necessary to spin the yarns from unset staple; that is, from staple which has never been exposed to live steam or high temperature. The yarn was then tumbled in skein form to encourage the formation of kinks in yarn. Then the tumbled skeins were exposed to boiling water or live steam to set the twist and kinks permanently. Setting takes place very quickly, so quickly, in fact, that it is impossible to carry out the setting and tumbling simultaneously, for in that event the setting occurs before sufficient kinking has time to take place.

Variations in the appearance of rugs of this type can be made by varying the twist in the yarns, by balancing the twist, or by using unbalanced twist. Unbalanced twist gives a more kinky yarn and a coarser texture. The degree of twist setting can be varied by spinning the yarn from a blend of set and unset staple.

Turn now to the problem of pilling, the formation of balls of fiber on the surface of uncut pile nylon rugs during service. Pilling can occur in fabrics of all staple fibers, but it shows up most objectionably in fabrics made from fibers which are so strong and tough that the pills do not wear off during service. This is ordinarily true of nylon and polyester fibers which possess this degree of strength and toughness. Hence the fabrics must be so constructed and finished as to prevent the formation of the pills in the first place.

Early qualitative studies, showed that pills resulted from raising of a fuzz on the surface of the fabric, followed by self-entangling of the fibers in the fuzz to form pills. Later a quantitative study was made in which the pertinent variables, namely the density, length, and the nature of the fibers composing the fuzz were varied systematically. It was found, as one might expect, that pill formation did not occur unless certain minimum lengths and concentrations (fibers/unit area) for the fibers in the fuzz were exceeded. These minima varied with the nature of the fibers making up the fuzz.

Subsequent studies showed that the relatively long fibers in the fuzz are generally formed by pulling out loops of filaments until one end of the filament comes loose from the yarn. As might be expected, factors such as increased twist or the application of finishes which increase frictional forces reduce the frequency with which filament loops are pulled out during service. Reasoning one step further, it should be possible to simulate the early stages of normal wear by a vigorous brushing of the fabric. This would pull out most of the filament loops which would otherwise be pulled out during service. If the resulting long-lengthed fuzz were then sheared off, it should be possible to prevent subsequent pilling during service.

H. E. Stanley and R. H. Pike of our Textile Re-

search Laboratory have applied these principles to the case of uncut loop pile rugs. Their work is so new that this account must be regarded as a progress report. It is based mainly upon data collected using an accelerated pill test which comprised tumbling of 8 in. squares of carpet with $\frac{1}{8}$ in. thick rubber strips and several cloth balls (to provide lint) in a home clothes dryer for 10 hr. Pilling was graded visually on a scale of 1 for no pilling and 5 for extremely bad pilling (see Figure 4). Ratings made in this manner correlated quite well with similar ratings made on carpets exposed to the traffic of 32,000 persons, as shown in Figure 5.

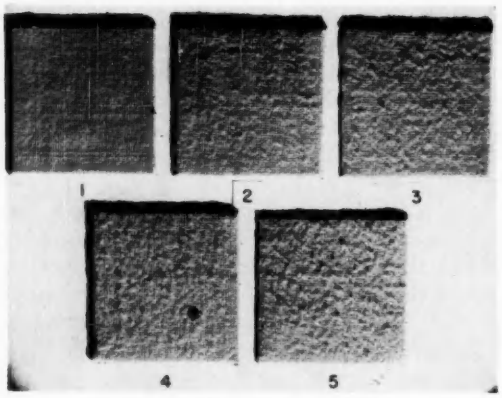


Fig. 4. Visual rating of pilling.

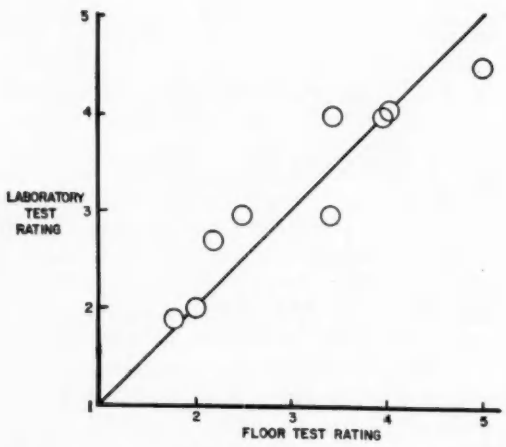


Fig. 5. Correlation of laboratory and floor test of pilling.

Examination of pills formed on uncut pile nylon rugs disclosed that many of the pilled fibers showed evidence of having been pulled through poorly bonded sections of the backing. This suggested that if the fibers in the loops were anchored more thoroughly by the latex applied to the backing, there might be a reduction in pilling. This was found to be the case. Many of the commercial latices have poor adhesion for nylon. A GRS latex was found which gave a distinct reduction in pilling; however, this improvement alone was not enough.

Examination of nylon rug yarns spun on the woolen system disclosed that short lengths of them contained many poorly oriented nylon fibers which could be pulled out in service, even from well-anchored tufts, to form long fibers and pills. For example, when such yarns were cut into 1-in. lengths and the filaments subsequently separated out, some were found to be 3–3½ in. long and 15% were over 1½ in. long. Rugs woven from this yarn pilled severely. A comparable cotton system yarn had only 4% of the fibers over 1½ in. in length and pilled much less. A worsted system nylon yarn had only 2% of fibers over 1½ in. in length and gave a rug sample which pilled hardly at all.

When rug samples which pilled severely were subjected to two cycles of wire brushing to pull out these long filaments followed by shearing to cut them off, the brushed samples were found to pill much less. Figure 6 presents data showing the effect of both brushing and shearing and the application of an effective GRS latex. Rugs with ratings of about 2 or less are thought likely to give acceptable performance in service.

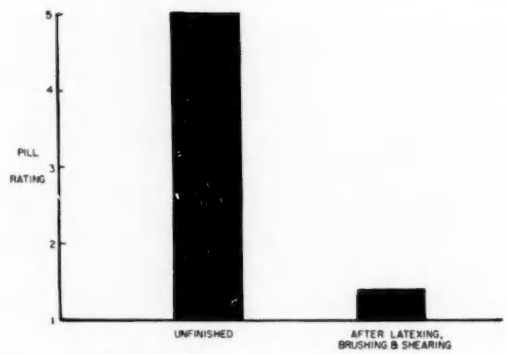


Fig. 6. Finishing to control pilling.

These and other developments in the dyeing field are eliminating the "bottlenecks" which formerly prevented the styling of a full line of nylon rugs. Aesthetic properties are beginning to approach the superior functional properties of nylon rugs.

Sheen Gabardine from Dacron and Rayon

A more complex example, one involving two fibers and the attainment of both aesthetic and economic goals, is that of the development of a sheen gabardine from Dacron polyester fiber and rayon. Previous to the work presented here, gabardines had been made from these fibers by blending 65% of 3 den./filament Dacron staple with 35% of rayon staple. Constructions and finishing procedures were similar to those used on all-rayon gabardines. These fabrics pilled severely and had an unattractive hand or feel which has been described by some as "mushy" (too soft and deficient in liveliness). Attempts had been made to overcome these deficiencies by increasing the twist, by using plied yarns rather than singles yarn, by increasing the number of picks and ends in the fabric, and by resin treatment. While the better fabrics resulting from these studies did not pill, they were lacking in aesthetic appeal being described as "boardy," heavy in weight and having a "hard" handle. They cost too much, due principally to the use of plied yarns.

The key to solving this problem lay in constructing the fabric from singles yarns spun from a blend containing mostly or all 6 den./filament Dacron and subsequently finishing the fabric by close shearing and careful singeing. By using 6 den./filament Dacron staple (which inherently pills less than 3 den.) and by doing a good job of shearing and singeing (in this case brushing is not necessary), pilling can be substantially eliminated. The heavier filament denier also improves the crease resistance, liveliness, and feel of the fabric. These effects are shown by comparing the three basic fabrics shown in Table II and Figure 7. The desired economic goal was attained by using singles yarns.

High-Low Shrinkage Principle

A principle which greatly extends the range of aesthetic effects can be achieved by the blending of different fibers—the mixed shrinkage principle.

Following several lines of reasoning, it was decided to spin the yarn from a blend of two acrylic staples, one having a high shrinkage and the other almost no shrinkage. As hoped, when such yarn was boiled off in water, it increased greatly in bulk. The hand was also improved. This combination has come to be known in the trade as high-bulk Orlon.[5] It can be produced from either tow or staple. Its discovery played a major role in winning for Orlon acrylic fiber a high proportion of the sweater market.

Further studies soon showed that this high-low shrinkage principle, combined with appropriate fiber and denier blending provided the fabric designer many new degrees of freedom for varying the feel, cover, and the bulk of fabrics woven from staple yarns.

Consider for the moment a yarn spun from a mixture of two fibers, one having high shrinkage, the other low shrinkage. When such a yarn is boiled off in yarn or fabric form, those fibers with high shrinkage contract in length and are drawn to the center of the yarn. Those with low shrinkage retain

[5] Orlon is Du Pont's registered trademark for its acrylic fiber.

TABLE II. Sheen Gabardines from Singles Yarn, 65/35 Dacron/Rayon

Denier of Dacron	Crease recovery* (A300, %)	Bending length†	Subjective liveliness‡	Pills/35 in.²§	
				Unsinged	Singed
3	77	1.55	5 (mushy)	283	8
4.5	80	1.77	3.5 (intermediate)	70	13
6	84	1.95	2 (not quite as good as 1)	17	0

* Crease recovery was measured by the Monsanto Test.

† Bending length was measured by the Hanging Heart Test, F. T. Pierce, *J. Textile Inst.* **21**, T377 (1930).

‡ The numbers under "Subjective liveliness" are averages of subjective ratings made by a panel of experts, where a rating of 5 represents an unwearable fabric and a rating of 1 is perfect.

§ Pilling was measured by the Random Tumble Tester, E. M. Baird, L. C. Legere, and H. E. Stanley, TEXTILE RESEARCH JOURNAL **26**, 731 (1956).

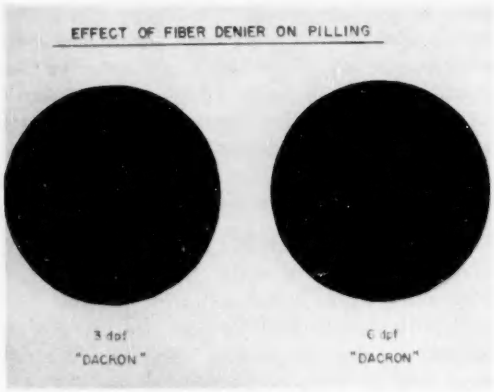


Fig. 7. Pill test fabric.

their length, are caused to form loops, and push toward the surface of the yarn and fabric. As a result it is the fiber which had low shrinkage initially that one feels in handling the fabric after boil-off.

Consider some practical examples; if one desires a lively fabric with a very soft handle, it can be achieved by constructing the fabric in the appropriate manner from a blend of low-denier staple with low shrinkage and high-denier staple with high shrinkage. Upon boil-off the soft, fine denier staple is forced to the surface where one can feel it. The long denier staple, though not on the surface, functions in the core of the yarn to improve liveliness. Conversely, a bitey tweedlike fabric can be made by forcing high-denier filaments to the surface using the same principle.

The two staples need not be of the same composition. For example, cotton can be forced to the surface in a Dacron/cotton blend, or wool to the surface in a Dacron/wool blend. A note of caution should be sounded in this connection, however. If the two fibers making up the blend differ widely in durability, the less durable fiber can wear away on exposed areas thus giving rise to a change in its appearance over areas subjected to greater wear. This will be particularly severe if the less durable fiber has been forced to the surface, and if the fibers are dyed to different shades. Consequently, the wise course of action is to end up with a blend of both fibers in the surface and to control the denier of the polyester fiber in the surface in such a manner that it assists the aesthetic contribution of the second component.

This mixed shrinkage principle can also be used to achieve substantial improvements in fabric cover, a much less thready appearance, a higher bulk, and in some cases a substantial reduction in pilling. All of these were to be expected except perhaps the effect on pilling. We believe that the shrinkable fibers lock the fibers in place by contracting in length and by taking a permanent set during the boil-off. This inhibits fuzzing, the first step in pill formation.

In Table III are summarized measurements on 3×2 sheen gabardines made from a blend of 55% Dacron polyester fiber and 45% wool, which show these latter effects.

Blends

Having considered how blends of different fibers can be manipulated to control aesthetic properties, it would be a mistake not to note that fabrics from certain specific blends are beginning to be recognized as having combinations of properties which can be achieved in no other way. In other words, these blends are functionally sound, not "gimmick" blends. In several areas the mythical "battle of the fibers" is becoming the "marriage of the fibers."

The most recent development of great importance is the story of Dacron and cotton. First manufactured only four years ago, this blend is now used in millions of yards of fabrics in at least 25 end uses ranging all the way from ladies' dresses, blouses, and slips to men's suits, shirts, and heavy work clothing. Dacron staple, usually at least 65%, is intimately blended with cotton. Dacron contributes crease resistance, neatness retention, and ease of care or wash-wear properties which last for the life of the garment. Cotton contributes freedom from static, attractive aesthetics and styling possibilities. Comfortwise, the blend has an improved balance of moisture properties. Cotton increases the rate of

TABLE III. Effect of Fiber Shrinkage on Fabric Properties

Boil-off shrinkage of polyester fiber component, %	Fabric properties		
	Thickness, in.	Bulk, cc./g.	Pills/ 35 in.²*
1	0.027	2.51	275
13	0.030	3.01	10

* By Random Tumble Tester.

wicking of perspiration and Dacron adds quick drying to minimize any feeling of dampness.

Dacron/cotton blends are also finding favor with the producers of fabrics because of the ease with which they can be dyed and finished to bright, fast shades with a most attractive hand.

Fabrics with attractive patterns are illustrative of what can easily be produced using yarn dyeing techniques. The yarn is wound onto perforated stainless steel tubes, loaded into a circulating machine, and dyed first under pressure with disperse colors at 250° F. or lower; vat colors are applied subsequently to the cotton in the customary manner.

Fabrics in solid shades are dyed by a continuous Thermosol method. Dispersed and vat colors are padded onto the fabric which is subsequently dried in a flue dryer. It is then heated in a hot air oven for 1 min. at 400° F. to cause the disperse colors to migrate into the Dacron. The fabric subsequently passes through a reducing bath which solublizes the vat dye and causes it to migrate into the cotton. An oxidizing bath then develops the vat dye.

Dacron/cotton blends are finished by easy modifications to usual cotton finishing procedures. The fabric is first desized, scoured, mercerized, washed, dried, heat set, and singed. This suffices to prevent pilling of the Dacron in service. Subsequent finishing steps are the same as customarily used on cotton fabrics. Such Dacron/cotton fabrics have an attractive feel.

In intimate apparel such as slips and pajamas, the most important fabric is a modification of this blend in a very desirable luster obtained by using a continuous filament warp of nylon and filling it with a blend of Dacron and cotton.

Blends of nylon and cotton are coming into use, but for different reasons. A number of very successful dress fabrics have made use of a continuous filament warp with a cotton filling to yield a fabric with an unusually attractive luster and sufficient strength despite its sheerness.

A strictly functional use is the reinforcement of cotton with 25–50% of nylon. Thus a 3-yr. wear test has shown that denims and twills containing 25% nylon blended in the warp gave 70% longer wear life than similar all-cotton garments. Gloves containing 50% nylon in the warp lasted an average of 2.2 times as long as similar all-cotton gloves.

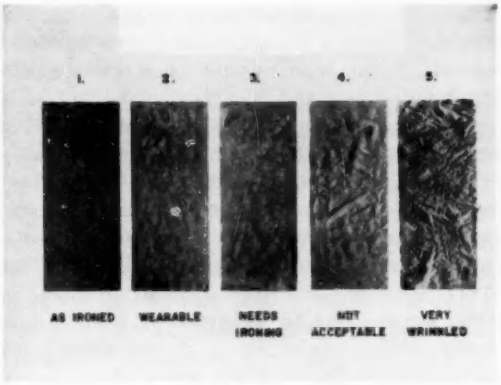


Fig. 8. Wrinkling scale.

Automatic Wash-Wear

Having strayed into the area of functional performance by way of blends of nylon with cotton, let us devote the rest of this discussion to researches which are paving the way to superior functional performance for end-use articles made from polyamide and polyester fibers. Let us consider the researches of R. W. Peterson, G. D. Rawlings, H. E. Stanley and P. R. Wilkinson of our Textile Research Laboratory presented at the 1956 meeting of the Textile Research Institute, which are pointing the way to completely automatic maintenance of wash-wear garments.

These investigators studied the wash-wear performance of garments as a function of the variables of fabric construction and finishing, and of washing and drying cycles. Their most startling disclosure was that an ordinary household rotary dryer operated

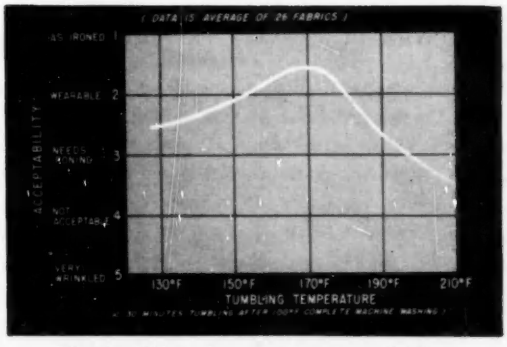


Fig. 9. Effect of temperature on wrinkling during tumble drying.

at about 170° F. could be used as an ironing machine to remove wrinkles formed in the better wash-wear garments during washing and extraction cycles or indeed during wear.

Using a visual scale for measuring wrinkling, Figure 8, these investigators showed that a tumble-drying temperature of approximately 170° F. (see Figure 9) gave the most complete removal of wrinkles without removing the permanent creases or pleats. One half hour of tumbling at the optimum temperature was adequate to remove wrinkles inserted by wear or by the washing cycle. Good tumbling action was required. It was found necessary to continue the tumbling action during a 5–10 min. cooling cycle or else to remove the garments promptly from the dryer and hang them up to cool off, else wrinkles were inserted as the garments lay in pile, cooling off.

The key to the action of a tumble dryer on polyamide and polyester garments lies in the fact that the garments have previously been heat set in the unwrinkled condition by fabric finishing and pressing treatments. When tumbled at 170° F., the heat increases the rate of recovery from wrinkles imparted at low temperature during wear or washing, and tumbling flexes the fabric, overcoming the inter- and intra-yarn frictional forces which operate to prevent recovery of the individual yarns. The temperature of the dryer is not high enough to "unlock" bonds formed in the fibers during the original heat setting of the fabric or during ironing. Thus the tumble dryer offers potential for "pressing" not only strictly wash-wear garments, but also those of high polyamide or polyester content which are not washed, but have become wrinkled after repeated wear.

It is much too early to write a treatise on how to obtain optimum automatic wash-wear properties, yet we have compared enough fabrics to begin to draw some tentative generalizations. In the first place, Dacron polyester fiber is superior to all of the other fibers we have tested in wash-wear performance. Increasing yarn diameter, stiffness, and filament denier improves wash-wear performance of shirting weight fabrics from either filament or spun yarns. Fabric constructions which permit movement of the yarns improve wash-wear performance; thus knits are better than woven fabrics. A marked improvement is obtained in going from a plain weave to an Oxford weave to a 2×2 basket weave to a 3×3 basket weave. In loose constructions, filament yarns give more mobility than spun yarns. In blends, a concentration of at least 65% Dacron is desirable.

These principles can be combined. Thus by weaving an Oxford construction using a filament Dacron warp of 70 den. and a Dacron/cotton 40 singles spun yarn filling, we have been able to obtain exceptionally good wash-wear performance stemming from the high Dacron content, the high mobility of filament yarn, and the freedom of motion of the Oxford weave; yet the fabric had the aesthetics and spun appearance of a broadcloth. This construction, greatly magnified, is shown in Figure 10.

In Figure 11 is shown an automatic wash-wear suit recently unveiled by Haspel Brothers, Inc. who

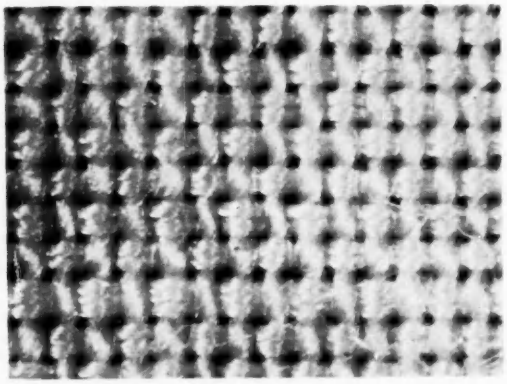


Fig. 10. Oxford weave with the appearance of a broadcloth.

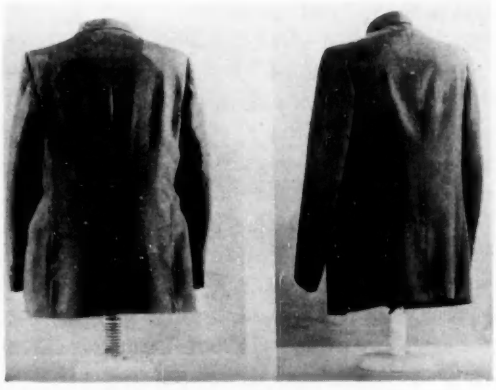


Fig. 11. Automatic wash-wear suit.

pioneered the first wash-wear suits four years ago. This suit contains 65% Dacron polyester fiber, 25% rayon, and 10% mohair. Note its excellent appearance after having been washed and tumble dried.

During this discussion we have considered a wide variety of textiles made from polyamide and polyester fibers. The examples have been chosen to illustrate the many recent advances in technology which are enabling us to build a level of aesthetics into these textiles worthy of the superior functional properties which come much more easily. It is a source of very considerable satisfaction that these advances are not passing unnoticed by those whose business it is to be familiar with the best in textiles. As evidence of this recognition I should like to quote a paragraph taken from an article in *House Beautiful*, September 1956, page 102, entitled "The New Sophistication of Synthetics":

"In this room the synthetic fabrics stand on their own merit because they are fresh, well-designed, adaptable, quite apart from their easy maintenance. They are showing the results of fruitful design experiment in their almost limitless colors, textures, patterns, and weaves, frequently combined or blended with other materials. These are no aesthetic misfits, for synthetics now belong, as certainly and appropriately as such old, natural standbys as silk, cotton, wool, and leather."

Manuscript received October 24, 1956.

National Cotton Council of America
1957 Cotton Research Clinic

The following papers were presented at the 1957 Cotton Research Clinic of the National Cotton Council of America, held February 27, 28, and March 1 in Savannah, Georgia. Other papers presented at the Clinic appeared in the June issue. Reprints of the entire proceedings, bound in a cover, will be distributed by the Cotton Council.

Increasing Cotton Carding Production

J. F. Bogdan

School of Textiles, North Carolina State College, Raleigh, N.C.

Abstract

Means for obtaining a 50% increase in cotton carding production rates without lowering quality are described. Test results for cotton yarns carded at rates up to 100 lb./hr. are given.

Introduction

High quality and high production are naturally opposed in carding. As every carder knows, reducing the production rate of his carding machines is a simple way to improve the quality of his webs. Unfortunately, production requirements preclude the application of this directly simple solution to the problem of obtaining improved quality. The carding production level of a mill is dictated by the balance between quality, production capacity, and manufacturing costs.

Carding production rates are increased simply by increasing the size of the production gear. This increases the rate at which the lap is fed into the machine without affecting the draft, so that the delivery rate equals the feed rate less the material removed as waste. Unfortunately, yarn quality deteriorates with increased production rates, though not as rapidly or as much as is commonly believed. This lowering of quality with increasing production is to be expected. At higher rates of through-put, the lickerin, cylinder, and flats are forced to act on larger tufts of fiber per unit area of card clothing, with the result that these elements cannot possibly do their work as well as at lower production rates. This is true for a given set of speeds and settings.

However, consider an elementary case in which the card clothing on a particular card is in need of replacement, but the quality of the product being manufactured is acceptable for the purpose. By replacing the damaged clothing it should be possible to: (1) maintain the quality level at a higher production rate, (2) obtain improved quality at the original production rate, or (3) both improve quality and increase the production rate somewhat. No one will deny that changes in card settings and speeds affect quality, and the accumulative benefits derived by the effects of certain changes in speeds and settings allow the same choice of balance between quality and production as did our example of the replaced card clothing.

This interaction between quality and production forms a basis for achieving the production increases

described in this report. The method consists of first improving the quality of carding, and then balancing the quality at near the original value by increasing production rates until that point is reached.

Figure 1 may help one to understand the meaning of this point. Suppose that a card with defective clothing produces a product whose quality level against production falls on line A. At a particular production rate P_1 the quality is Q_1. If the clothing is renewed and the mechanical condition of the machine is otherwise improved, then the quality level for the whole range of productions is raised to line B. At production rate P_1 the new product quality is Q_2. If the original quality level Q_1 is acceptable to the customer, then the production rate for the reconditioned machine can be increased to P_2 to bring the quality level back down to Q_1.

Figure 2 shows the balance between carding quality and carding production rates: (1) an initial balance, (2) an improvement in carding quality balanced by an increase in production rate to bring the quality level to the original value, and (3) an improvement in carding balanced at the original production rate by the acceptance of the improved product.

This report describes the pertinent results obtained from a project, jointly sponsored by 16 mills, which had for its purpose the investigation of means for increasing cotton carding production rates beyond existing commercial levels.

Experimental

The results are based on work in which full-size production machines were used under conditions duplicating mill processing conditions as closely as possible. The cottons used (Table I) were supplied by the supporting mills in picker-lap form.

To localize the factors affecting carding production, laps of all 16 cottons were processed at the recommended speeds and settings developed in previous carding research at N.C. State College, except for whatever one variable was being studied. The variable, such as a speed or setting, was tested at several conditions ranging from subnormal to abnormal. After results of individual variables were obtained, tests in which the variables were integrated were made.

In most cases, fiber was carded for 2 hr. and only the sliver from the last ½ hr. of the run was processed into yarn. Variations in yarn strength, yarn evenness, yarn appearance, wastes, etc. were recorded for each sample processed.

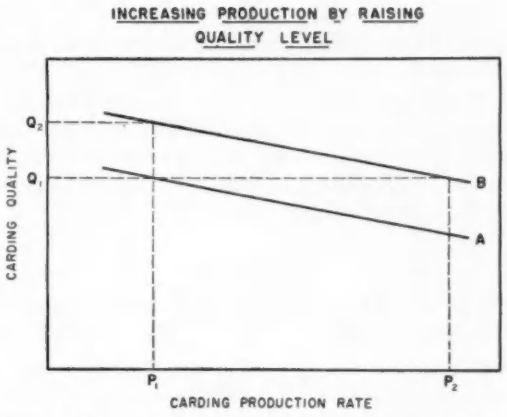


Fig. 1. General relationship between carding production rate and quality.

This standardization of card running time is necessary to minimize the effect of changing quality with card running time. Table II shows no significant change with running time in the average yarn strength of 14 cottons. Figure 3, however, shows that there is a change in yarn appearance from one half-hour interval to another. It will be noted, too, that yarn spun from the sliver produced at the end of the first half-hour is less attractive in appearance than that produced at longer running times. This is undoubtedly the result of the less uniform deposition of fibers from the cylinder onto the doffer during the initial

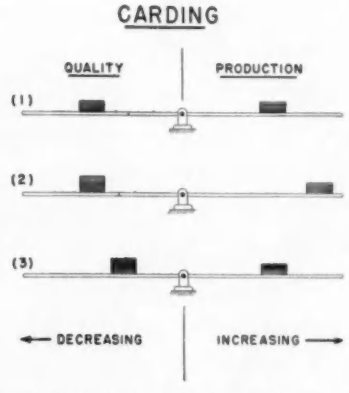


Fig. 2. Balance between carding quality and carding production rate.

loading period of the carding cycle when fibers are being deposited into the lightly loaded wires of the cylinder.

In all cases, yarns furnished by each mill and data on the manufacturing organization for each mill were used as controls. Additional controls were provided by the manufacture of yarns at N.C. State with the mill's manufacturing organization.

Discussion

Effect of Carding Production Rate on Yarn Strength and Appearance

Table III shows the comparison of yarns produced using mill settings at the mill production rates with those produced with the settings shown in Table V at a production rate approximately 50% above the mill rate. It will be noted that the count strength product did not suffer as a result of the increase in production. It was actually higher in the case of 13 of the 16 cottons used, and the total carding waste averaged slightly lower for the higher production rate. An inspection of the yarn boards produced shows that the appearance of the yarn produced at the higher rates of production is of better grade.

Figure 4 shows yarns obtained from $1\frac{1}{16}$ in. Middling cotton and from a waste mix composed of card strips. The panel on the right is that obtained by processing on our machinery using the settings furnished by the mill and the mill production rate; the panel on the left represents yarn manufactured from sliver produced with these same mill settings at an increase of 50% in carding production rate; the panel in the center is produced by carding material at an increase of 50% above the mill production rate figure using the recommended speeds and settings given in Table V.

Varying carding production rates from 10 to 100 lb./hr. shows no great variation of count × strength product against production rate (Table IV, Figure 5). The recommended speeds and settings were used for this experiment. The effect on yarn appearance of a carding production rate of 100 lb./hr. is not nearly as disastrous as is commonly believed (Figure 6).

Though a ball-bearing doffer comb will function at carding production rates up to about 30 lb./hr., it will not doff the web at higher production rates without

TABLE I. Cottons Used

Mill	Staple length, in.	Grade
H	1	M
I	$1\frac{1}{32}$	BM
J	$1\frac{7}{16}$	Fully good to extra
K	$1\frac{1}{16}$	SM
L	$1\frac{1}{16}$	SM, M
M	$1\frac{1}{16}$	M
N	$1\frac{3}{32}$	SM
O	$1\frac{1}{16}$, $1\frac{3}{32}$	M
P	$1\frac{1}{8}$	—
Q	$1\frac{1}{16}$	SLB
R	$1\frac{1}{32}$, $1\frac{1}{16}$	Card strips
S	1	Raw cotton, strips and noil
T	$\frac{15}{16}$	LM
U	$1\frac{1}{32}$	SLM
V	$1\frac{1}{16}$	M
W	$\frac{15}{16}$, 1	M, SLB

TABLE II. Effect of Card Running Time on Count × Strength Product

(Average of 14 Cottons)

Running time, hr.	Average CS
$\frac{1}{2}$	1992
1	1973
$1\frac{1}{2}$	1964
2	1979

TABLE III. Effect of Increased Carding Production on Count × Strength Product

	N.C.S. Carding		
Mill	Mill settings Mill carding rate	N.C.S. settings 50% Increase in production	CS Units difference
H	1956	2093	+137
I	2072	2200	+128
J	2795	2832	+ 37
K	2107	2128	+ 21
L	2152	2264	+112
M	2213	2247	+ 34
N	2307	2358	+ 51
O	1889	1921	+ 32
P	2199	2203	+ 4
Q	2090	2248	+158
R	1566	1652	+ 86
S	1396	1409	+ 13
T	1987	1938	− 49
U	2341	2324	− 17
V	2555	2653	+ 98
W	2242	2234	− 8
			Mean + 52
Avg. carding waste, %	6.2	6.1	

TABLE IV. Effect of Carding Production Rates on Count × Strength Product

Cotton: 1 in. M			Cotton: $1\frac{1}{16}$ in. M		
Production, lb./hr.	C × S	Uster integrator	Production, lb./hr.	C × S	Uster integrator
10	2358	11.6	11	2082	16.0
19	2288	11.7	21	1909	16.7
32	2290	12.0	33	1979	16.8
38	2264	13.5	40	1947	17.1
46	2285	12.5	50	1965	17.4
60	2274	12.7	60	1917	16.8
70	2264	13.3	70	2055	18.5
80	2185	13.8	80	1985	18.6
100	2234	12.9	98	2028	20.0

excessive vibration, due to the increased reciprocating speed required. To achieve experimentally the high production rates required, an Abington "Rolaslivup" web doffing attachment was substituted for the comb (Figure 7). The substitution of the pair of rotating rollers for the reciprocating comb solved the problem of vibration at excessive speeds. We hasten to re-emphasize that a means of doffing the web at high doffer speeds is not alone the means for achieving high production rates; changes which improve quality must first be made.

Lickerin Speed

The improvement in quality which results from increases in the speed of the lickerin have been described previously [1, 2]. With a cylinder speed of 165 r.p.m. the practical limit for lickerin speed is about 800 r.p.m. When the lickerin speed is raised beyond this level, the lickerin strips material from the cylinder onto itself and becomes loaded, resulting in poor quality. The lickerin speed can be raised beyond this level if the cylinder speed is increased correspondingly. Table VI shows waste, count × strength product, and uniformity figures for experiments in which the cylinder speed was varied from 165 to 350 r.p.m. and the lickerin speed from 800 to 1690 r.p.m. on a number of cottons, maintaining a constant production rate. The appearance of the yarns produced with the high cylinder and lickerin speeds is improved. This is demonstrated vividly when processing a waste mix (Figure 8); the material is cleaned substantially more by the action of the higher lickerin speed.

In another experiment on 1 in. Middling cotton, the ratio of lickerin speed to cylinder speed was maintained constant and the cylinder speed was varied from 83 to 250 r.p.m. (Table VII). The yarn produced at the higher speeds was again better than that produced at the lower speeds (Figure 9). This is expected because of the better opening of fiber tufts which occurs at the high lickerin speed.

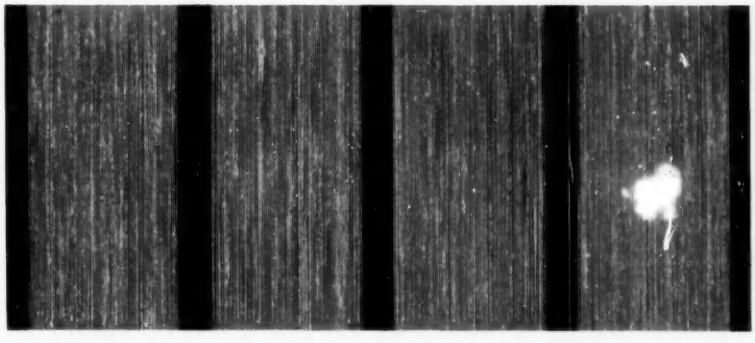
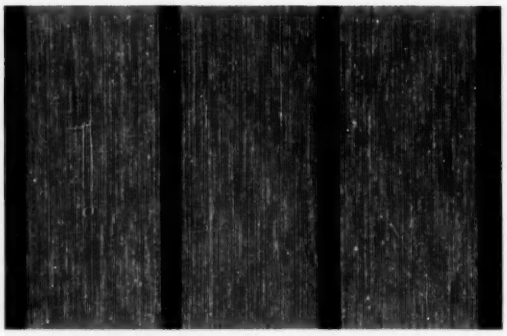
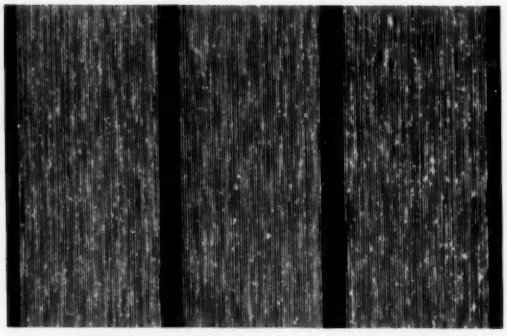


Fig. 3. Effect on yarn appearance of card running time after stripping.



i. 50% increased production with mill settings. ii. 50% increased production with our settings. iii. Regular production.

Fig. 4a. Effect on yarn appearance of a 50% increase in carding production rate on 1 1/8 in. Middling cotton.



i. 50% increased production with mill settings. ii. 50% increased production with our settings. iii. Regular production.

Fig. 4b. Effect on yarn appearance of a 50% increase in carding production rate on a waste mix.

Sliver Weight and Doffer Speed

A given carding production rate can be obtained by a number of combinations of sliver weight and doffer r.p.m. The question arises as to whether it is better to produce a heavy sliver with a low doffer speed or a light sliver at a high doffer speed. In this set of experiments (Table VIII), the delivered card sliver weight was varied from 40 to 70 gr./yd. while the doffer speed was adjusted to maintain a constant production rate per hour. The yarns produced show no advantage of the lighter card sliver weight over the heavier in regard to yarn strength, though the appearance of the yarn (Figure 10) is generally better when the lighter card sliver is processed. This is

TABLE V. Recommended Carding Speeds and Settings

Make	Saco-Lowell	Whitin
Speeds		
Lickerin, r.p.m.	800	750
Cylinder, r.p.m.	165	
Doffer, r.p.m.	Depends on production	
Flats, in./min.	3	
Doffer comb, cycles/min.	Depends on production	
Settings, thousandths of inch		
Feed plate to lickerin	7	
Mote knives to lickerin		
Top	7	
Bottom	7	
Top mote knife to feed plate, in.	1¼	¾
Bottom mote knife to bars, in.	1⅛	1¼
Top edge of back plate to flats	10	22
Mote knife angle, deg.	30	27
Lickerin screen to lickerin		
Without continuous stripper		
Back	17	64
Middle	17	29
Front	17	17
With continuous stripper		
Back	68	
Middle	34	
Front	10	
Lickerin to cylinder	7	
Back knife plate to cylinder		
Top	10	
Bottom	10	
Flats to cylinder		
Back	7	
Intermediate	7	
Intermediate	9	
Intermediate	10	
Front	12	
Flat stripping comb to flats	15	
Front knife plate to cylinder		
Top	22	
Bottom	22	
Doffer to cylinder	5	
Doffer comb to doffer	17	
Cylinder screen to cylinder	*Flange*	
	With	*Without*
Back	29	29
Center	187	68
Front	375	187
Continuous stripper		
Setting, width of band, in.	1¼	
Speed, r.p.m.	1750	
Type of lickerin screen	Bar	
Type of cylinder screen	Bar	

TABLE VI. High Cylinder and Lickerin Speeds

Cotton	RPM		% Carding waste	CS	Uster integrator
	Cylinder	Lickerin			
1 in. M	165	800	4.7	2266	12.2
	350	800	5.4	2192	13.0
	350	1690	6.3	2181	12.3
$1\frac{7}{16}$ in. Egyptian	165	800	6.1	2589	13.2
	350	800	8.6	2367	14.5
	350	1690	8.8	2618	13.4
$1\frac{1}{16}$ in. M	165	800	6.2	2036	16.8
	350	800	6.6	1920	15.9
	350	1690	7.9	2053	16.4
Card strips	165	800	13.8	1699	17.6
	350	800	13.6	1644	19.9
	350	1690	14.8	1686	20.1
$1\frac{1}{16}$ in. M	165	800	5.2	2516	13.4
	350	800	5.5	2570	12.7
	350	1690	5.5	2584	12.5

TABLE VII. Varying Cylinder and Lickerin Speeds

Cotton	RPM		% Carding waste	CS	Uster integrator
	Cylinder	Lickerin			
1 in. M	165	800	4.0	2325	13.6
	83	400	3.8	2288	14.7
	250	1210	4.7	2352	13.0

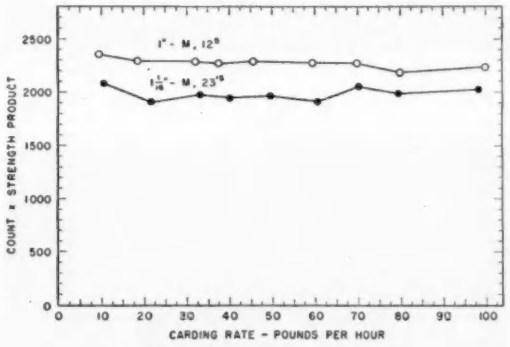


Fig. 5. Effect of carding production rate on count × strength product.

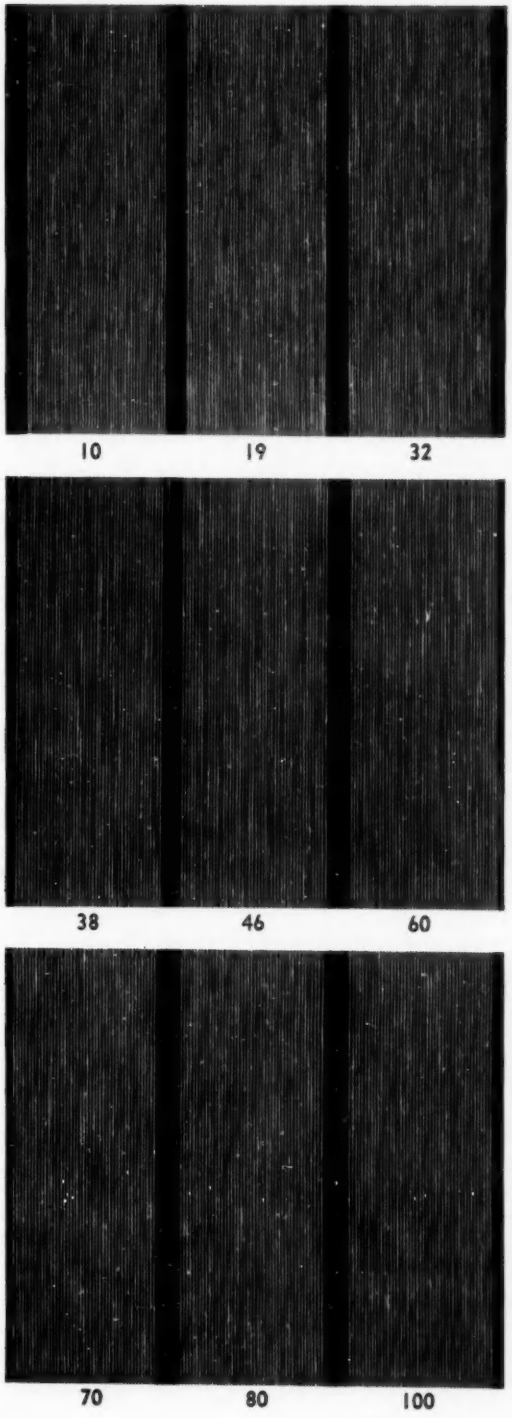


Fig. 6. Effect on yarn appearance of carding production rates (lb./hr.) varying up to 100 lb./hr. 1 in. Middling cotton.

TABLE VIII. Varying Sliver Weight and Doffer Speed

Cotton	Sliver weight, gr.	Doffer, r.p.m.	% Carding waste	CS	Uster integrator
1 in. M	60	9.5	4.3	1984	16.0
	40	14.2	4.4	2098	13.7
	70	8.2	4.4	2069	13.3
$1\frac{7}{16}$ in. Egyptian	44	4.5	6.1	2640	15.2
	40	5.0	6.2	2623	15.0
	70	2.8	6.3	2701	15.9
$1\frac{1}{16}$ in. M	50	6	5.6	2052	15.8
	40	7.5	5.5	1909	16.8
	70	4.3	6.1	1957	16.6
$1\frac{1}{16}$ in. M	47.5	8.5	4.3	2503	14.6
	40	10.1	4.0	2500	14.1
	70	5.8	4.3	2472	16.5

TABLE IX. Varying Flat Settings

Cotton	Flat settings 1/1000 in.	% Carding waste Total	Flats	CS	Uster integrator
1 in. M	7, 7, 7, 7, 7	4.2	1.9	2281	14.8
	7, 7, 9, 10, 12	3.5	1.7	2142	14.7
$1\frac{7}{16}$ in. Egyptian	7, 7, 7, 7, 7	6.2	2.6	2678	16.6
	7, 7, 9, 10, 12	5.1	2.1	2694	15.8
$1\frac{1}{16}$ in. M	7, 7, 7, 7, 7	5.7	2.6	1961	16.8
	7, 7, 9, 10, 12	5.0	2.2	1973	16.5
$1\frac{1}{16}$ in. M	7, 7, 7, 7, 7	4.5	2.1	2354	12.0
	7, 7, 9, 10, 12	3.7	1.7	2351	13.2

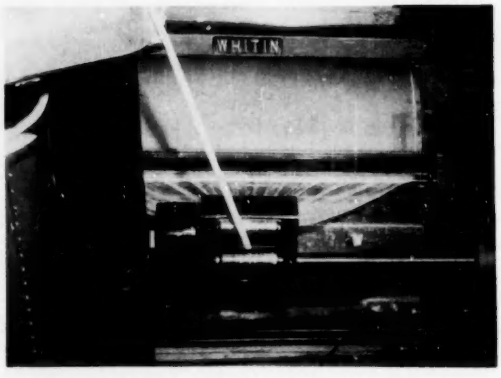


Fig. 7. Abington "Rolaslivup" web doffing attachment.

probably a result of better fiber control in the first drawing operation afforded by the lower bulk of material fed. Carding quality alone should be the same for this set of experiments; the only difference in mechanical action is the rate of collection of material on the doffer. The action at the feed roll, lickerin, cylinder, and flats is the same for a given set of experiments in Table VIII.

Card Settings

Using progressive flat to cylinder settings of 7, 7, 9, 10, 12 thousandths of an inch from the back stand to the front reduces flat strips and total carding waste substantially (Table IX). The quality of the yarn produced with these settings compared with that produced with uniform settings of 7 thousandths of an inch shows no difference in yarn strength or yarn appearance. Since the back flats do the brunt of the work, it is necessary to maintain a close setting of

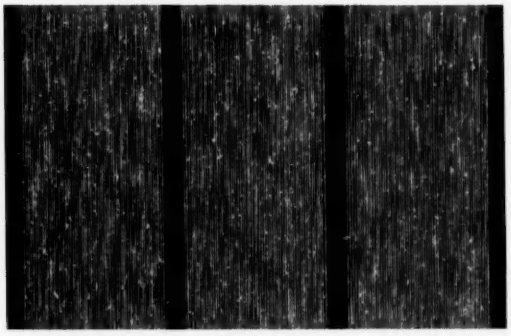


Fig. 8. Effect of yarn appearance on high cylinder and lickerin speeds.

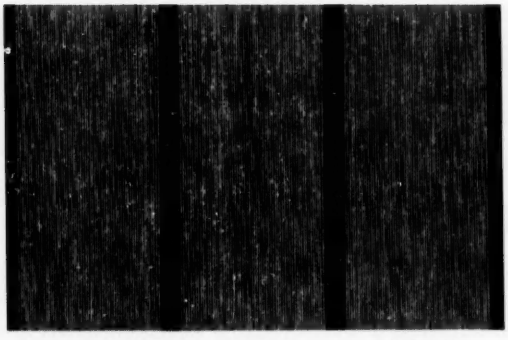


Fig. 9. Effect on yarn appearance of varying cylinder and lickerin speed.

flats to cylinder only at the two back stands. This modified requirement for close flat settings may help to allay the fears of many manufacturers who object to maintaining uniform close flat settings in production.

When processing on a card equipped with metallic clothing on cylinder and doffer, it is found that using flats to cylinder settings of 0.015 in. results in lower carding waste and produces a stronger yarn than a setting of 0.007 in., except in the case of a waste mix (Table X).

The action between the cylinder and the doffer is a "carding" action; that is, the directions of the wire points of these elements are opposed; therefore, a close setting of the doffer to cylinder is required to obtain adequate transfer of fibers from the cylinder to the doffer. Let us assume a ridiculous example in which the doffer to cylinder setting is opened to $\frac{1}{4}$ in. It is apparent that the surface of the cylinder would become loaded with a heavy band of fiber before transfer to the doffer would occur. This is a means for producing a neppy web for processing into novelty yarns where a nubby effect is desired, but it has no place in normal processing. It is true, conversely, that the closer the doffer is set to the cylinder the more fiber it will strip from the cylinder. This keeps the cylinder free of excessive waste, permitting an improvement in carding quality and allowing the stripping cycle to be lengthened. How close a setting between doffer and cylinder a mill can maintain in production depends on the mechanical condition of the card and the firmness of the flooring.

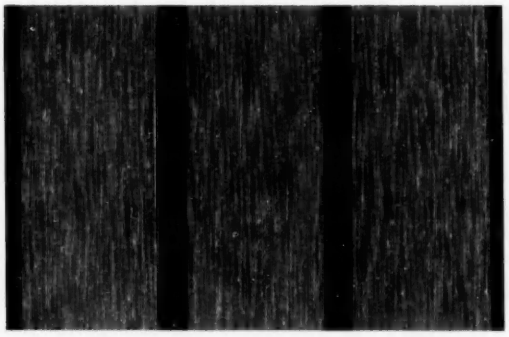


Fig. 10. Effect on yarn appearance of varying sliver weight and doffer speed while maintaining a constant production rate.

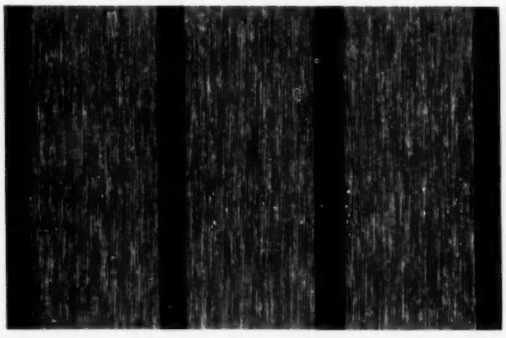


Fig. 11. Effect on yarn appearance of doffer to cylinder settings.

Table XI shows the result of varying the doffer to cylinder setting from 3 thousandths to 7 thousandths of an inch. It will be noted that carding waste increases with the wider settings and yarn strength decreases. The yarn appearance is best for the close doffer to cylinder setting (Figure 11).

It is a popular misconception in industry that a close setting of feed plate to lickerin will result in lowered yarn strength. That this is not true is shown by the results reported in Table XII. The yarn produced with a feed plate to lickerin setting of 4 thousandths of an inch is as strong as that obtained by using a setting of 15 thousandths of an inch. The yarn appearance is best for the closest setting reported.

Card Clothing

There appears to be little difference in total per cent card waste or in yarn strength between material carded on a card clothed with 100s/110s wire and one clothed with 110s/120s. Use of the finer wire produces a yarn of slightly better appearance for the longer stapled cottons. Carding of a waste mix is better accomplished on the coarser clothing (Table XIII).

Lickerins clothed with 8 strands per inch, 4 points per inch wire produce stronger yarns than lickerins clothed with 15 strands, 5 points per inch wire (Table XIV). The appearance of the yarn obtained by using the coarser wire is as good as, or better than, that for the finer clothing. There is little difference in carding waste.

Lickerin wire with a less acute point, such as is

used for carding synthetics, produces a yarn of better appearance and, generally, of better strength than does normal cotton-type wire, but the total carding waste is increased by about 1½% on the average (Table XV). This increase results from an increase in motes and fly waste because of the lower holding-power of the obtuse point of the wire.

Modifications

Inverting the mote knives from their normal position (Figure 12) decreased motes and fly waste by more than 1% without affecting yarn strength, uniformity, or appearance adversely (Table XVI). The decrease in motes and fly is explained by the decrease in the openings between feed plate, mote knives and lickerin screen which prevent the loss of good fiber.

Reversing the mote knives from their normal position (Figure 13) resulted in no advantage in waste saving, yarn strength, or appearance.

Replacing the curved lickerin bonnet, indicated by the broken line in Figure 14, with an improvised cover of the shape, indicated by the heavy lines, re-

TABLE X. Flats to Cylinder Settings on Card with Metallic Clothing

Cotton	% Carding waste		CS Product		Uster integrator	
	0.007 in.	0.015 in.	0.007 in.	0.015 in.	0.007 in.	0.015 in.
1 in. M	3.7	2.8	2098	2216	15.5	14.4
1 7/16 in. Egyptian	3.8	3.8	2506	2616	15.8	17.4
1 1/16 in. M	4.5	3.6	1888	1977	18.4	17.0
1 1/16 in. M	3.7	3.2	1930	2102	19.3	17.4
Card strips	12.2	10.4	1638	1434	21.9	20.9
1 1/16 in. LM	3.8	3.3	1944	1954	17.8	18.3
Mean	5.3	4.5	2000	2050	18.1	17.6

TABLE XI. Doffer to Cylinder Settings

Cotton	% Carding waste			CS Product			Uster integrator		
	0.003	0.005	0.007	0.003	0.005	0.007	0.003	0.005	0.007
1 in. M	—	4.2	4.3	—	2281	2172	—	14.8	15.0
1 7/16 in. Egyptian	5.6	6.2	7.1	2639	2678	2466	16.3	16.6	18.5
1 1/16 in. M	5.2	5.7	6.8	1996	1960	1960	17.4	16.8	17.5

TABLE XII. Feed Plate to Lickerin Settings

Cotton	Settings (1/1000 in.)	% Carding waste	CS	Uster integrator
1 in. M	4	4.6	2218	14.3
	7	4.7	2266	12.2
	15	4.6	2257	13.9
1 1/16 in. M	4	5.9	1997	16.2
	7	6.2	2036	16.8
	15	6.1	1933	18.3
1 1/16 in. M	4	3.7	2008	16.1
	7	3.9	1874	17.6
	15	3.8	2029	17.5
1 1/16 in. LM	4	4.2	2160	16.8
	7	4.1	1944	16.5
	15	4.3	1980	15.6
1 1/16 in. M	4	5.2	2857	13.9
	7	4.5	2516	13.4
	15	4.5	2747	12.5

TABLE XIII. Card Clothing Wire Density

Cotton	Card clothing		% Carding waste	CS	Uster integrator
	Cylinder	Flats and doffer			
1 in. M	100s	110s	4.7	2093	12.7
	110s	120s	4.7	2133	13.5
1 1/32 in. M	100s	110s	5.8	2200	14.7
	110s	120s	6.4	2197	13.9
1 7/16 in. Egyptian	100s	110s	6.9	2885	12.2
	110s	120s	7.1	2958	12.7
1 1/16 in. M	100s	110s	6.1	2247	16.1
	110s	120s	5.9	2247	15.2
1 1/16 in. M	100s	110s	4.7	1921	19.4
	110s	120s	4.5	2018	16.9
Card strips	100s	110s	12.6	1652	18.3
	110s	120s	13.7	1596	18.7

TABLE XIV. Effect of Lickerin Points per Inch

Cotton	Points/in.	% Carding waste	CS	Uster integrator
1 in. M	8 × 4	4.0	2325	13.6
	15 × 5	3.9	2125	14.6
1 7/16 in. Egyptian	8 × 4	6.6	2721	16.2
	15 × 5	5.8	2452	16.2
1 1/16 in. M	8 × 4	5.7	2058	15.6
	15 × 5	5.3	1885	17.7
1 1/16 in. M	8 × 4	4.5	2096	17.8
	15 × 5	4.7	1945	17.7
1 1/16 in. M	8 × 4	4.6	2573	12.8
	15 × 5	4.5	2499	12.6

TABLE XV. Type of Lickerin Wire Point

Cotton	Type wire	% Carding waste: Total	% Carding waste: Motes and fly	CS	Uster integrator
1 in. M	Cotton	4.7	1.5	2266	12.2
	Synthetic	6.2	3.0	2300	13.2
1 7/16 in. Egyptian	Cotton	6.1	2.0	2589	13.2
	Synthetic	8.7	3.5	2787	13.9
1 1/16 in. M	Cotton	6.2	1.9	2036	16.8
	Synthetic	7.5	3.6	1996	17.0
1 1/16 in. M	Cotton	3.1	1.5	1874	17.6
	Synthetic	6.5	3.8	1996	17.8
1 3/16 in. LM	Cotton	4.1	2.1	1944	16.5
	Synthetic	5.4	3.3	1996	15.9
1 1/16 in. M	Cotton	5.2	1.3	2516	13.4
	Synthetic	6.5	2.1	2632	11.6

TABLE XVI. Effect of Inverted Mote Knives

Cotton	Mote knives	% Carding waste: Total	% Carding waste: Motes and fly	CS	Uster integrator
1 7/16 in. Egyptian	Regular	6.6	2.3	2680	16.2
	Inverted	5.8	1.1	2603	15.2
1 1/16 in. M	Regular	5.7	2.1	2058	15.6
	Inverted	4.8	0.8	2060	16.5
1 1/16 in. M	Regular	4.5	1.9	2096	17.8
	Inverted	3.8	0.8	1965	17.7
1 3/16 in. LM	Regular	4.4	2.0	1814	17.1
	Inverted	3.0	0.7	1818	17.1

duced the total carding waste, mainly because of a saving in motes and fly waste (Table XVII). The waste thrown out by the action of the lickerin is lower in this scheme because of a reduction in the force of the air currents within this system. The uniformity of the yarn is generally better when the modified lickerin cover is used.

Increasing the length of the lickerin screen along the curved dimension decreases motes and fly waste substantially, effecting a saving in total carding waste (Table XVIII). The appearance of the yarn produced by using the longer screen is as good as that obtained by using the shorter screen. The choice of the proper lickerin screen, considering the lickerin speed used, is the simplest way to control the amount of motes and fly waste removal desired.

Moving the flats intermittently according to the plan shown in Table XIX resulted in a general im-

TABLE XVII. Modification of Lickerin Cover

Cotton	Lickerin cover	% Carding waste: Total	% Carding waste: Flats	% Carding waste: Fly	CS	Uster integrator
1 in. M	Regular	4.7	1.6	1.7	2093	12.7
	Square	4.3	1.7	1.2	2147	12.2
1 1/16 in. SM	Regular	6.3	1.8	2.8	2264	12.9
	Square	5.6	2.2	1.6	2375	13.4
1 1/16 in. M	Regular	6.1	1.9	2.2	2247	16.1
	Square	5.3	2.2	1.4	2265	15.6
1 1/16 in. M	Regular	5.5	1.8	2.1	2653	11.3
	Square	5.2	2.1	1.4	2492	9.9

TABLE XVIII. Lickerin Screen Length

Cotton	Length of screen, in.	% Carding waste: Total	% Carding waste: Fly	CS	Uster integrator
1 in. M	7 1/4	6.3	2.7	2181	12.3
	8 1/4	4.4	0.7	2172	11.7
1 7/16 in. Egyptian	7 1/2	8.8	2.2	2618	13.4
	8 1/4	7.6	0.8	2659	14.1
1 1/16 in. M	7 1/4	7.9	3.3	2053	16.4
	8 1/4	6.1	1.1	1970	15.9
Card strips	7 1/2	14.8	7.2	1784	16.1
	8 1/4	12.2	3.6	1776	17.1
1 1/16 in. M	7 1/2	5.5	1.8	2584	12.5
	8 1/4	4.7	0.7	2369	13.0

TABLE XIX. Intermittent Movement of Flats

Cotton	Flat speed, in./min.	Movement	% Carding waste	C × S	Uster integrator
1 in. M	3	Constant	4.7	2266	12.2
	6	Move 1 min., pause 1.5 min.	4.6	2145	12.5
	6	Move 1 min., pause 5 min.	4.4	2244	12.2
$1\frac{7}{16}$ in. Egyptian	3	Constant	6.1	2589	13.2
	6	Move 1 min., pause 1.5 min.	6.4	2775	13.8
	6	Move 1 min., pause 5 min.	5.7	2810	13.7
$1\frac{1}{16}$ in. M	3	Constant	6.2	2036	16.8
	6	Move 1 min., pause 1.5 min.	6.3	2226	15.1
	6	Move 1 min., pause 5 min.	5.6	2048	15.4
$1\frac{1}{16}$ in. M	3	Constant	5.2	2516	13.4
	6	Move 1 min., pause 1.5 min.	5.1	2640	11.7
	6	Move 1 min., pause 5 min.	4.5	2590	10.4

Fig. 12

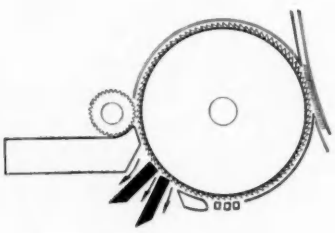


Fig. 13

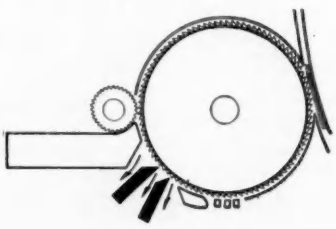


Fig. 14

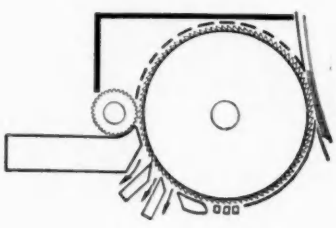


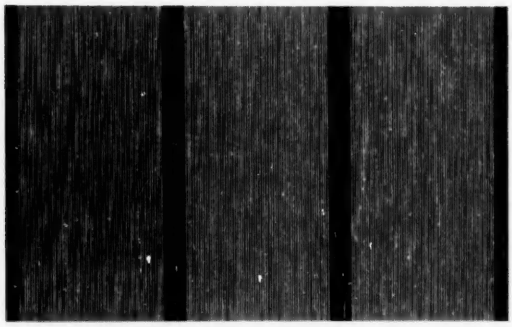
Fig. 12. Inverted mote knives. **Fig. 13.** Reversed mote knives. **Fig. 14.** Modified lickerin cover.

provement in yarn strength and yarn uniformity over that obtained by moving the flats at their normal constant speed. The yarn produced by the cycle of running the flats at 6 in./min. for 1 min. and stopping the flats for $1\frac{1}{2}$ min. appeared to give the best yarn appearance (Figure 15).

Acknowledgments

The author is indebted to Henry K. C. Woo for his valuable contributions to this project.

Special acknowledgment is due the following mills whose financial support made this project possible: Avondale Mills; The Borden Manufacturing Com-



a. Continuous (3 in./min.).

b. Intermittent (6 in./min.); move 1 min., pause 1.5 min.; motion of flats—regular direction.

c. Intermittent (6 in./min.); move 1 min., pause 5 min.

Fig. 15. Intermittent movement of the flats.

pany; The China Grove Cotton Mills Company; Cross Cotton Mills Company; Deering Milliken Research Trust; Fieldcrest Mills; Highland Cotton Mills, Inc.; Joanna Cotton Mills Company; Linn-Corriher Mills Company; Morgan Cotton Mills, Inc.; Quaker Meadows Mills, Inc.; Shuford Mills, Inc.; Swift Manufacturing Company; Washington Mills Company; Waverly Mills, Inc.; West Point Manufacturing Company.

Literature Cited

1. Bogdan, J. F., TEXTILE RESEARCH JOURNAL **25**, 377–385 (1955).
2. Bogdan, J. F., and Feng, I. Y. T., *Textile World* **102**, 91–106 (May 1952).

Joanna's Report on Metallic Card Clothing

J. L. Delany

Joanna Mills Company, Joanna, S.C.

THE use of metallic card clothing, from a historical point of view, is not new. The wool industry has been using it for several generations. In a paper previously given before this Clinic, it was stated that on an extra width woolen card it had been running for over 60 years in one mill. In our own cotton textile industry we have the classic example of the Columbus Manufacturing Company who began installing metallic clothing on their cards in 1928, completing the installation over a 10-year period. It was my privilege to visit this fine mill in 1950 to see this clothing and I came away greatly impressed with its potential. The quality of the web was very good. The cleanliness of the roving and yarn was excellent. On looking over their cloth, one was easily sold on its good appearance and quality.

We decided to try this clothing on our cards at Joanna. Some of the earlier trials in other mills were made on a single card which offered but little in the evaluation of so great a project. For this reason we installed 10 cards and based our research on what could be called a substantial offering. The earlier installations at Joanna were somewhat tedious and time consuming. By the time the card had been stripped down to the bare cylinder and doffer about a day had passed. Then the next several days were spent in winding the base wire on which the top carding wire would be wound. The base wire installation is necessary to restore the normal cylinder and doffer working diameters. Here is where the factor of extra weight enters the picture. By all means management should clear with their engineers this matter of the load carrying capacity of their building. Somewhat in excess of 500 lb. weight will be added to each card clothed with metallic clothing.

After installing the base wire, it is absolutely essential that this be ground to a true and accurate surface. Unless this is done properly, the top wire will be uneven, will require excessive grinding to correct, and the sharpness of the tooth will be destroyed. On flexible, conventional clothing, the wire must be ground regularly and often to produce quality work. On metallic wire clothing, in my opinion, it should be ground only upon its installation or when repairs are needed and at this time only enough to allow a true and level surface in order to set to gauge.

Initial Problems

Management as a whole did not look too favorably on the method of installation used by the earlier fitters. Too much old-fashioned line shaft driven makeshift devices of uncertain stability were used. There was too much splicing of the wire, using flame-heated soldering irons. For some reason electric irons were not popular. There was too much employee time lost in just sitting down resting while the old-style bare cylinder grinding wheel made its

interminable trips to and fro across the cylinder and the doffer. Too often only one grinding wheel could be used, thus prolonging the job out of all proportion. The fact that the top wire was sent to the mill in standard lengths and required several splices to fill out the length needed for the cylinder, and for the doffer, didn't suit too well. After all, when cards must be set to 0.001 in., it can well happen that a defective lining of the spliced ends may cause one end to be slightly higher than the other, which of course may be remedied only by excessive grinding in order to set the card properly. The fitter also needed a helper to assist in the installation, to fetch and carry, to turn the hand crank when necessary, to help with the shifting of the belts, and all in all to use as a flunky. Then after the top wire had been fitted, it was still quite a task to rebuild the card. Most of the earlier fitters could fit about four cards in five weeks, with a helper as well as plenty of assistance from the card grinders. The size of the job too had a bearing, in that on a large scale job extra equipment would be made available so that more than one card at a time could be worked on.

In spite of these objections we at Joanna put on our trial sets, checked them out, and found we were doing a superior carding job with the metallic card clothing. The web was smoother, there was a definite reduction in neps, and surprisingly there seemed to be a marked increase in the efficiency of the card. The waste taken out on the flat strip was darker and had less long fibers. Our waste dealers weren't too happy about this.

From a mechanical standpoint, metallic card clothing has several advantages. It needs no grinding. Stripping is absolutely minimized and the waste removed is mostly impacted matter such as seed hulls, woody substances, and belt dressing. There is a minimum of lint. Should there be a smash, it may not be scratched up as one would do with flexible filet. However, it can be repaired by cutting out the bad section and rewinding in a new length of wire. This is an advantage over the flexible wire for if that becomes flattened out the entire cylinder or doffer must be discarded, representing a total loss.

Modern High-Precision Equipment

During the last several years a new type of high precision installation equipment has been made available to the industry by a southern manufacturer. We were never happy about the old-fashioned installing gear mentioned above. This was a continual source of frustration to both management and supervision at Joanna. The wire itself was no different from that which we had been using, that is superficially. Actually, we found it to be very exact in height. It also came in two exact lengths, one each for the cylinder and for the doffer, so that no splicing was required so far as the top wire was concerned.

On the day of the trial set of the new clothing, both card room supervision and management were amazed at the fantastic job of precision installation we had received. Nothing had been left to chance, each single operation had been very carefully, and powerfully, motorized. New, high speed grinders were on hand, one each for the cylinder and the doffer. Dial micrometers were fitted on each end of the grinders to measure accurately the amount of stock taken off at each traverse and to ensure holding to a minimum the amount ground off the top wire. The auxiliary equipment was just as surprisingly complete. There was a one-man, remote control, card drive which would allow one man to do the actual installation. Whatever extra help was necessary to handle the lifting of the rolls on and off the card would be supplied by casual assistance from the card tender or grinder. Although the top wire is supplied in one continuous length, and this is highly essential, the base wire can not be so delivered. It is too heavy and it would be impractical and unnecessary to have it this way. For this reason splicing is necessary and to expedite this chore a precision quick-action welding device is used. This is a very practical device, and one result which we can see on our cards is the freedom from rust stain and discoloration coming through the top wire which occurs when ordinary soldering is done. The stains are caused from the soldering acids used which for some reason or other bring on oxidation. Just how serious this may be we don't know. Up to now it has proved no problem. Improvements were also made in the H wire used at the selvages of the units clothed.

Problem with Doffer Journals

Shortly after our initial installations were begun, we were confronted with the fact that most of our doffer journals were badly worn. On regular fillet clothing the settings are not too close and, furthermore, there is a certain amount of give in the flexible

clothing. Not so with the metallic. This is set to 0.005 in. between the doffer and cylinder and there is absolutely no give to this clothing. We then started a program to replace the journals as we clothed the card. This proved to be too expensive. On our cards the journal costs about $48.00; the cheeks of the card also contain built-in bearings and these units run about $50.00 per side. We had been told that it would be against good shop practice to build up these cast-iron journals and then turn them down to exact size because welding a cast-iron journal caused excessive distortion. A distorted journal would be impractical to use and must be discarded, causing complete loss of the repair. We had a new type metal spraying device coming in at this time and this proved to do the job very well indeed. However, we did weld about 15 or 20 journals with not a single instance of distortion. These journals are still running after five years. Our problem with re-using the cheeks was solved by our shop supervisor who suggested planing off $\frac{1}{16}$ in. from the joining surface of the lower bearing, clamping the top and bottom bearing together, and reaming the bearing to standard size. This we have been doing now for about five years without creating any difficulties.

There were two things more which we developed. One was a winch to enable one man to lift the doffer out of the card; with two men, or with four, this is a very unsafe operation due to the close quarters between adjoining cards as well as the excessive weight of the doffer itself. The winch with plenty of power, mounted on a ball bearing caster frame, gave ease of handling to a rather frightening task. There was one more job here. To remove a doffer journal by driving it out with hammers is doing it the hard way as well as the long way. Our shop supervisor came up with a beautiful rig which utilized a 20-ton jack acting against a special frame by means of which one man could take out the old journal and put in a new one in less than 30 min.

Answers to Inquiries

Since we made our early installations, we have received numerous inquiries concerned with such factors as maintenance, operation, production, and cost. The following selected list of questions and our replies should be helpful.

Along with the questions and answers, four tables, comprising some of the data obtained in test runs at Joanna are shown, as well as a chart which illustrates our experience in the reduction of neps.

TABLE I. Card Clothing Comparisons, August 1954

	Neps 100 sq. in.	Waste grains per flat	Oz. fly per hr.
Regular fillet	34.8	13.7	1.8
"A" metallic	28.2	10.3	1.5
Semi-metallic	33.0	15.2	1.6
865 r.p.m. licker reg.	32.2	11.5	2.4

Question: Doesn't it take much longer to install metallic clothing than regular clothing?

Answer: It takes approximately 30 hr. for a trained man to install properly the metallic clothing. The time for installation on the regular clothing may vary from 6 to 20 hr. However, there are usually two men required to install regular fillet, while only one man is needed for the installation of the metallic wire. Needless to say, that in the installation of either a certain amount of added help is usually provided by the grinders.

The breakdown on metallic clothing is approximately 50% for the cylinder, 25% for the doffer, and 25% for the base wire.

Question: Can the ordinary card grinder install metallic card clothing?

Answer: No. It may be installed only by a manufacturer's agent who comes equipped with very special installation equipment. A local man, who is of good intelligence and has some mechanical ability, may be trained by the manufacturer to install this clothing. This training period may take anywhere from two to four weeks depending on local conditions.

TABLE II. Test of Carding Egyptian Karnak-1 7/16" Cotton on Cards Clothed with Metallic Wire with Different Points per Mesh and Angle of Tooth

Clothing on cylinder		
Points per inch	20	14
Angle of tooth	80°	80°
Clothing on doffer		
Points per inch	10	14
Angle of tooth	50°	80°
Card sliver Gr./yd.	39.8	40.4
Neps 100 sq. in. web	22.0	26.5
Fly oz./hr.	1.29	1.39
Flat waste Gr./flat	6.70	7.00
Warp yarn count	57.54	57.62
Skein break in lb.	54.8	55.0
Break factor	3153	3167
Yarn imperfections/50 yd.	16.3	21.4

TABLE III. Yarn Comparisons

Regular Fillet vs. Metallic Card Clothing

	Fillet	Metallic
Size warp	31.31	31.94
Break, lb.	70.6	67.9
Break constant	2210	2169
Neps per 50 yd. (wp)	79	72
Size filling	40.52	40.10
Break, lb.	48.5	52.8
Break factor	1965	2117
Neps per 50 yd. (wp)	89	72

Question: How much more does metallic clothing cost than regular clothing?

Answer: The material cost is almost twice as high on the metallic as it is on the flexible fillet regular clothing. This cost includes the price of the base wire which of course is only installed one time. Should it become necessary to reclothe the card, the original base wire is still there and its cost will not be included in any further reclothing.

Question: How long will M.C. last compared with R.C.?

Answer: The normal life of R.C. is from 5 to 10 years. Its life is controlled by the frequency of grindings, if ground lightly or heavily; the hours per week of operation and whether or not full three shifts. Six-day weeks are normal practice. Then there is also the policy of management toward replacing fillet having definite wear, or being unable to deliver stock of a quality to meet standards. All of these affect the life of the regular clothing.

With M.C. there is no grinding hence no loss in the height of the wire. Some manufacturers make the claim that the actual wear on the tooth does not occur on the tip, but at a point about one-fourth down the front of the tooth. In this way, the manufacturer claims the tip of the tooth does not wear but actually grows sharper with its normal life. Under these conditions the life of the M.C. may actually be tied in with the life of the card, barring unforeseen accidents.

Question: Isn't it true that a small smash on regular clothing may be scratched up whereas such a smash on metallic clothing must be cut out and replaced?

Answer: Yes, smashes will necessitate replacement. However, the entire filet isn't taken off; only the damaged circumference is cut out and replaced. This may be less of a disadvantage, for on large smashes, which utterly ruin regular clothing, only that part of the wire that is damaged need be replaced.

Question: Approximately how much per year per card does it cost to operate on regular clothing as against metallic clothing?

Answer: The normal life of regular clothing is approximately one-fourth the normal life of metallic clothing. This is debatable, but based on this premise we have arrived at a figure of about $22.50 per year on the M.C. as against $47.00 per year on the R.C. This is entirely based on the actual cost of the different clothings and does not include any other factor.

Question: How often is grinding required on metallic card clothing?

Answer: Grinding is required only at the time of the installation and at any later date when a major repair has been made. It then becomes necessary to grind in order to level the wire for the purpose of accurately setting the card to gauge.

Question: Can metallic clothing be set as closely as regular clothing?

Answer: Yes, even closer. On regular clothing the card grinder develops a "feel" for his setting. He may use what he calls a tight or a loose setting. On metallic clothing it is set the same way the valves on your automobile are set, "go" or "no go." As a general rule metallic clothed cards are set much closer than regular due to the rigidity of the wire.

Question: How frequently do smashes involving reclothing the card occur on metallic clothing?

Answer: Our experience has been about three cards per year. Most of these repairs were on the doffers and were caused by water getting on the doffer and causing a build-up of stock. This experience was on about 200 cards.

Question: Are not close settings dangerous?

Answer: Yes. A regular clothed card has a certain amount of "give." The wire is flexible and will bend. On metallic clothing there is no give at all. The wire is perfectly rigid. For this reason, lumps, hard ends, and folded laps, must be kept out of the card. The web must not be allowed to run around the doffer and build up for the closer settings will make a smash much sooner than on a regular card.

Question: How about flaking or ragged selvages on metallic clothing?

Answer: This difficulty also occurs with a startling amount of similarity on regular clothing as well as on metallic. We think the answer lies in better fitted

screens, screens made concentric with the cylinder, or possibly screens of a different type. Up to now we have no answer to this question.

Question: What about the use of continuous strippers on cards equipped with metallic clothing?

Answer: They would be entirely useless and wasteful. The fine needles will effectively keep the lint on top of the regular wire, hence minimizing stripping. On metallic wire there is only a minute amount of lint in the wire at any time. Foreign matter such as impacted wood, seed hulls, belt dressing, and other such material may be removed only by the mechanical action of a wire brush.

Question: Doesn't the use of metallic clothing take out less waste on the card than regular clothing?

Answer: Yes, the metallic clothing is more selective in getting the waste and not the spinnable fibers. The strips will be lowered at least one full grade and will also contain less lint and more trash. There will also be less lint in the fly.

Question: If less waste is taken out on metallic clothing than on regular clothing, isn't this stock coming out in a later process as clearer waste?

Answer: We have no direct answer to this question. We feel that we aren't taking out less waste at the card, merely less spinnable fiber that should stay in our product rather than enrich the waste dealer.

Question: Isn't it true that the web from the metallic wire doffer has a bad tendency to fall off and end up under the card as waste?

Answer: This was true on earlier installations. However, during the latter part of 1955 a different type doffer wire was brought out which completely overcomes this trouble.

Question: What is the difference between the old- and the new-type doffer wire?

Answer: The new wire has less teeth per inch and more angle to the wire. Where the old wire had 14 teeth per inch with 80 deg. angle tooth, the new wire has 10 teeth per inch and 50 deg. angle tooth. On some of our trials we went as low as 6 teeth per inch with very good results in the web, waste, and finished yarn.

Question: Were there any other effects from the new doffer wire other than keeping the web from falling off?

Answer: Yes, much to our surprise we found a drastic reduction in spinnable fiber in the card strips. We think the new wire is more efficient about picking up the stock from the cylinder. It seems to get the lint off the cylinder the very first trip around, thus preventing the card from grinding up the fibers into waste that will come out as strips, fly, and neps.

Question: What about the new-type wire used on the card cylinder?

Answer: Coarse wire with high angle on the cylinder will not card. The stock transfers very poorly from such a cylinder to the doffer. This we found out under actual test.

Question: Metallic wire may be satisfactory for coarse goods but what about fine count, long stapled cottons?

Answer: We are running metallic clothing on at least three different mixes. One is a fairly low grade type used in yarns from 6.00's to 18's and carded at a rate of about 15 lb./hr. The second mix is our standard shade cloth mix of S.M. $\frac{1}{32}$-in. cotton, carded at 8.00 lb./hr. and spun into 30's and 40's. The third mix is Egyptian Karnak, $1\frac{7}{16}$-in staple and carded at a rate of 4.50 lb./hr. This is spun into 60's and 80's yarns. On a straight comparison test, our metallic cards on all three of these mixes produce a web having less neps and a stronger yarn usually having less imperfections per 50 yd., found on our imperfection counters. This latter was also verified by at least two outside agencies.

Question: How fast is it possible to card on metallic clothing?

Answer: There is no direct answer to this question. What we have found is that when the two types of clothing are run in competition to one another at any speed, the metallic clothing always gives the best job of carding as to quality of sliver and amount of waste.

TABLE IV. Comparison of Waste from 30 Cards on Shade Cloth

15 with Fillet Clothing
15 with Metallic Clothing

	Fillet, %	Metallic, %
Fly waste		
Lint content	40.78	44.88
Visible waste	48.26	44.10
Invisible waste	11.00	11.08
Trash or total waste	59.26	55.18
Strips		
Lint content	75.30	84.18
Visible waste	18.84	10.10
Invisible waste	5.92	5.82
Trash or total waste	24.76	15.90

Question: Would metallic clothing be economically practical on waste cards?

Answer: We think metallic clothing will work well no matter where it is used. While we do run a substantial amount of waste, we prefer to use a special waste-type flexible fillet wire rather than metallic. We feel that there will come a day when we will use metallic wire on waste cards, but at present we are more interested in getting our regular production cards changed over.

Question: Does wetting the card affect the metallic clothing as badly as it does regular clothing?

Answer: No, on regular clothing the cloth foundation becomes wet and in the course of time the wire in the base will rust, break, and fall out. Since there is no fabric base to metallic clothing, there is nothing that ordinary drying out procedures will not quickly overcome, thus putting the card back into production quicker and with no lasting threats to its life.

Question: Will metallic clothing abolish the job of card grinder?

Answer: No, the card grinder will remain as the card setter. It is very essential that the card be set properly to perform adequately its task. Settings on M/C are much closer than on R/C and must be maintained more closely. Furthermore, no matter what clothing may be on the card, there are flats, screens, lickers, and other component parts to be set regularly. The total number of grinders may be reduced but his need, as above outlined, certainly makes him a much required man.

Question: What combination of the new-type wire teeth on metallic clothing gives the best results?

Answer: Our experience has led us to standardize on 80 deg. with 20 points per inch on the cylinder and 50 deg., 10 points per inch on the doffer.

The finer wire on the cylinder does not hold as much trash as the longer, heavier, earlier type tooth. It also does a superior job of carding, with less neps, smoother web, less lint in the waste. There is also a nice drop in the amount of imperfections in the finished yarn. The higher angle, coarser tooth on the doffer gives us a surface which will hold the web tightly, yet freely release the fleece at the comb. Due to the finer cylinder wire, there is also less impacted waste on the doffer surface.

Question: Is it possible to run a metallic clothed cylinder with a regular clothed doffer?

Answer: Yes, this was done on some of our earlier installations. Our purpose was to defeat the defect of the web falling off the doffer while carding. Our only recourse from the manufacturer was to grind the card very lightly. This would "rough-up" the tips of the wire and cause better web adhesion. To avoid this difficulty—before the remedy for this had been found in coarser doffer wire with more angle—the use of regular fillet wire was tried and proved effective in overcoming this trouble. From the standpoint of making a better web, a smoother yarn, or a stronger yarn, we could neither prove nor disprove its use. We decided to replace this on the point of having all cards uniformly equipped and set. We also wanted to cut out grinding as well as minimize stripping.

Question: What has been the semi-metallic wire experience at Joanna on flexible type wire having specially treated base and tips to compete against metallic wire?

Answer: We have tried several different types of flexible wire for which claims were made that there would be less stripping due to the increased height of the base clothing, as well as less grinding due to the extra hard point. There would also be a nep reduction. In as far as less grinding was concerned, this we found true. The wire is much harder, will stand up longer between grindings (based on the type cotton being carded), and extends grindings to three or four times per year rather than per month. We also found it necessary to strip these cards less often—about every 40 hr.

There was also a sharp nep reduction. Where metallic clothing cut neps about 25%, we found that this clothing cut neps about 15%.

This clothing can not be scratched up as one would

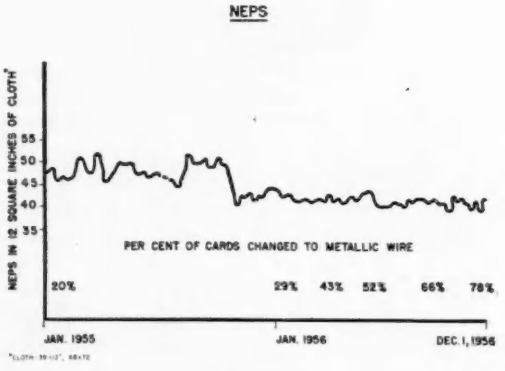


Fig. 1a.

repair a regular fillet. While it resists bung-ups it does not have any give and we lost several of the trial sets since their installation, due to bung-ups.

Question: What has been done in the use of metallic clothing on the flats?

Answer: J. W. and H. Platts Company make and supply a flat covered with special metallic clothing. This is made up of short pieces set into the flat in such a manner to be parallel to the wire on the cylinder. The manufacturer claims even greater than ordinary waste savings on this type flat. This company says that with the always clean cylinder and flat wire, the carding action is more efficient and the fiber is not drawn through a mass of dirty and filled up regular wire teeth, but is passed through the card with about one third less waste.

Question: What has been the experience at Joanna on different type flat wires?

Answer: Up to now we have tried several different types of flats covered with hardened wire. This is similar to the type clothing used on cylinders and doffers and for which claims have been made that it is as effective as regular metallic card clothing. Some grinding must be done on these flats but not as frequently as on the standard flat. We have found that there is a definite reduction in flat strips with no increase in neps in the web. Up to now, we have not proved out yarn or cloth tests.

Question: How effective is metallic wire on synthetics?

Answer: Personally, we have had little experience with synthetics. The manufacturer claims that it is even more effective on synthetics than on cotton. This is because there is no cleaning action and the card merely performs an opening and converting into sliver action.

We have been told by those in the synthetic field that there has been no fiber that they have not been able to card effectively on revolving flat cards equipped with metallic clothing. Naturally, the licker-in must be recovered with wire made particularly for synthetics. Regular cotton-type wire will hold the fibers and build up a mat of stock on the licker-in which prevents carding. Also, the flat settings must be opened up considerably. There are

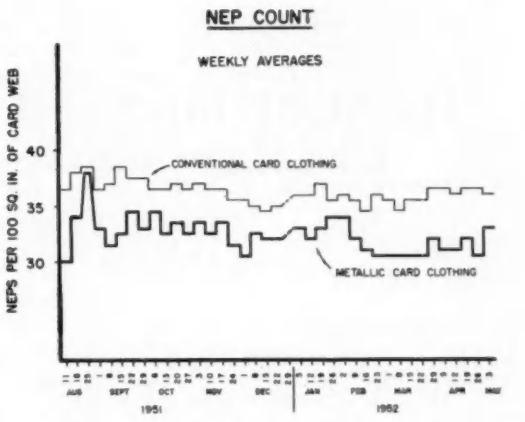


Fig. 1b.

other adjustments to be made which also would be made on any conversion from cotton to synthetics using regular flexible wire.

Question: What are the disadvantages of metallic clothing?

Answer: Its first cost is greater; it takes longer to install. It requires highly specialized installing gear. Card tenders and grinders need retraining. On earlier installations web falls off doffer. There are flaking and waste on selvages. This may be due to ill-fitted screens. Even minor smashes must be cut out and new wire spliced in. Greater care must be taken to keep hard lap ends out of card. Web must not be allowed to run around doffer and create a build-up for with extra close settings smash occurs.

Question: In a general way just what do you expect to gain from the use of M.C.?

Answer: What we have gained so far is a definite and positive nep reduction in our web, our yarns, and our fabrics. We are also saving a lot of spinnable fibers at the card that on regular clothing would have been taken out in the flat strips. We are minimizing stripping with its attendent savings in R/W and loss in C.V. We have eliminated grinding which is wasteful, unproductive, and time consuming. We have installed clothing which barring bad accidents will last out the life of the card.

The SRRL Integrated System for Opening and Cleaning Cotton—the Opener-Cleaner[1]

R. A. Rusca and R. C. Young

Southern Regional Research Laboratory,[2] New Orleans, La.

Abstract

An integrated system for cleaning cotton at textile mills is under development at the Southern Regional Research Laboratory. The theory and general design of the system and of one of its component machines, the Opener-Cleaner, are discussed.

The results of laboratory evaluations, using five commercial varieties of cotton, are presented. Comparisons of the processing performance of a conventional opening-picking line and an experimental line with the Opener-Cleaner are favorable to the experimental line. The Opener-Cleaner, alone, provides 35% cleaning efficiency and 0.3% lint loss at 1500 lb./hr. production.

Introduction

Before discussing the integrated system for cleaning cotton at textile mills, which is now under development at the Southern Regional Research Laboratory, it is worth-while noting the widespread adoption of mechanical and rough hand-harvesting methods which have brought about the need for improved cleaning equipment (Figure 1). It can be seen that machine harvesting has increased to almost 3.2 million bales during the past 6 years and that hand snapping of cotton accounts for about the same amount. These relatively trashy cottons are difficult to clean satisfactorily with existing textile equipment.

The program of the laboratory is directed toward systematically and scientifically developing a system for cleaning cotton at the mills, wherein the function of each machine is integrated and synchronized with every other machine. The idea of the SRRL system has been previously discussed [1]; suffice it to say that the system is now comprised of two machines: an Opener-Cleaner as the sole machine in the opening room and a Carding Cleaner as the sole cleaning machine in the picker room. A third machine, an Aerodynamic Cleaner, was also developed for use in the opening room which provided about 20% trash removal at 1000 lb./hr. production. It utilized a rotating slotted cone—something like an ice-cream cone with the closed end cut off—and a series of air jets, all enclosed in a dead air chamber (Figure 2). However, in the interest of simplicity, cost, and conservation of floor space, and at a slight reduction of over-all cleaning efficiency, the SRRL system has only the aforementioned two types of cleaning machines (Figure 3).

The Opener-Cleaner

The Opener-Cleaner is basically the SRRL Cotton Opener [2, 3] with built-in cleaning devices. It incorporates the opening and blending ability of the earlier Opener, requires less air to operate, has higher production and is slightly larger in size.

In its present form, the Opener-Cleaner utilizes a total of 9 lickerin type cylinders: 1 kicker cylinder, 4 opening cylinders, 2 cleaning cylinders, and 2 doffing cylinders (Figure 4). In comparison, the Opener has 1 kicker, 5 opening, and 5 doffing cylinders. Physically, the new cleaner is 18 in. longer and 2 in. lower than the Opener. Horsepower consumption is approximately the same.

The general relationship of the Opener-Cleaner cylinders is schematically depicted in Figure 5. None of the teeth intermesh. The basic concept of the

[1] Presented by R. A. Rusca at the 8th Cotton Research Clinic held at Savannah, Georgia, February 27–March 1, 1957.

[2] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

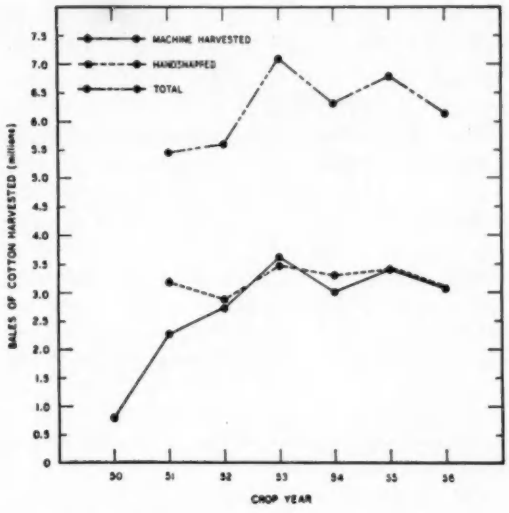


Fig. 1. Bales of cotton machine-harvested and hand-snapped, 1950–1956.

SRRL Cotton Opener is retained in the new Opener-Cleaner. The cotton fibers are never held firmly; they are always free to move in the direction of the greatest force. The cleaning cylinder, rotating at a higher surface speed than the opening cylinders, gently removes the finely divided fibers from the opening cylinders and passes the fibers over the cleaning devices. In turn, the doffer cylinder removes the fibers and casts them into a stream of conveying air.

Research at the laboratory has shown that wire-wound or gin-saw type toothed cylinders in combination with grid bars will not damage cotton fibers, provided (1) the cylinder-grid bar set up is properly designed, (2) the cotton is exceptionally well opened, and (3) the cotton is not fed to the cleaning cylinder by means of rolls, roll and plate, or any other mechanical device that firmly holds the fibers.

Definitions

Workers in industry and research use many terms interchangeably when discussing cleaning of cotton. Waste removal, trash removal, per cent waste, per cent cleaning, cleaning efficiency, fiber loss, lint loss, lint in the waste, rich waste, poor waste, and others are employed. To assist in interpreting the results to be presented, the terms used in this paper and the subsequent paper on the Carding Cleaner are defined as follows:

Per Cent Waste. The per cent of stock removed, by weight, of the total stock fed to a machine. This figure represents a combination of trash, motes, fiber and other components of the stock.

Lint in the Waste. The per cent, by weight, of the waste that is lint.

Trash in the Waste. The per cent, by weight, of the waste that is nonlint.

Cleaning Efficiency. The per cent, by weight, of the trash in the stock fed to a machine that is removed by the machine.

Lint Loss. The per cent of the lint removed, by weight, of the stock fed to a machine.

Trash and lint contents are usually determined by means of the Shirley Analyzer.[3]

For a true evaluation of the performance of a cleaning machine, it is necessary to determine either the cleaning efficiency and lint loss, or the per cent waste

[3] The use of trade names does not constitute an endorsement of the product.

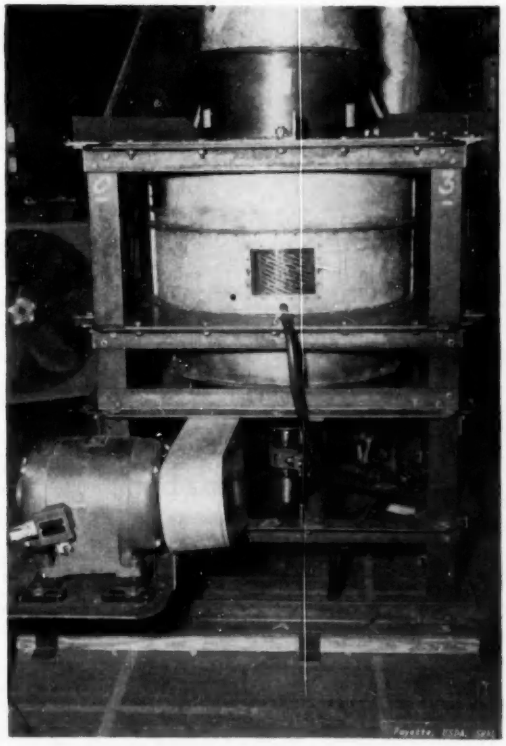


Fig. 2. Experimental aerodynamic cleaner.

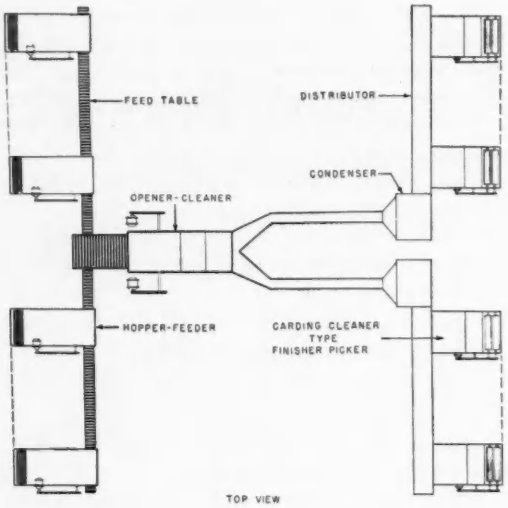


Fig. 3. SRRL integrated system for cleaning cotton in textile mills.

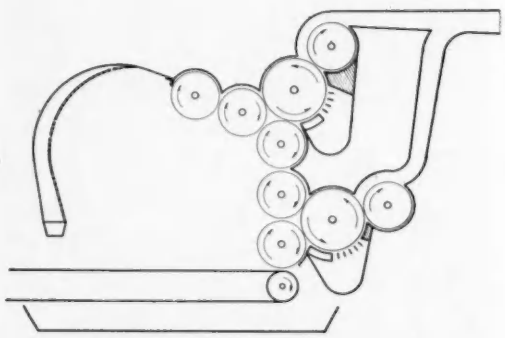


Fig. 4. Schematic diagram of the SRRL Opener-Cleaner.

and the lint and trash in the waste. In general, high cleaning efficiency is associated with high lint loss.

Experimental Procedure

Evaluations of the Opener-Cleaner were conducted in the textile processing unit of the Southern Laboratory. The opening-picking line is comprised of an automatic blending feeder, horizontal Buckley opener, cage section, porcupine-type cleaner, overhead condenser, hopper feeder, lattice belt, and a one-section picker with Kirschner beater which serves as a breaker and finisher picker (Figure 6). Four breaker picker laps laid on the lattice belt are fed to produce the finisher lap. This is called the "control" line. As indicated in Figure 6, the Opener-Cleaner line substitutes the Opener-Cleaner for the Buckley and porcupine openers.

Because the opening room has only one automatic hopper feeder, it was necessary to operate the Buckley and porcupine openers at 300 lb./hr. production. Sufficient cotton was initially accumulated in the picker line hopper feeder to allow the production of a picker lap at 350 lb./hr.

The Opener-Cleaner was hand-fed at the rate of 1500 lb./hr. from stock previously processed through the automatic hopper feeder. The stock delivered by the Opener-Cleaner was then hand-fed to the picker line hopper feeder at 350 lb. production.

One bale of each of five widely grown commercial variety cottons representing a range of grades, staples, and growing conditions was processed (Table I). The Coker 100 W.R. was not included in the study reported in this paper. Every bale was carefully sandwich-blended, and 50-lb. lots were withdrawn from the blended bale for each test. All tests were performed in triplicate. Processing stock weights were 13 oz. picker lap, 55 grain card, first

TABLE I. Variety and Physical Properties of Cottons Processed

Variety	Mean trash content, %	Classer's grade	Classer's staple, in.	Micronaire unit	Maturity,[1] %
Acala 4–42	3.2	SLM (Grassy)	$1\frac{3}{32}$	4.6	84
Wilds	3.6	M	$1\frac{1}{4}$	3.8	84
Coker 100 W.R.	4.8	LM	$1\frac{1}{16}$	4.4	86
Deltapine 15	7.0	LM	$1\frac{1}{16}$	4.4	88
Unknown	10.2	LM (SGO leaf)	$\frac{15}{16}$	3.9	80
Bobshaw	10.3	LM (SGO leaf)	$1\frac{1}{32}$	5.6	95

[1] NaOH method.

and second drawing sliver, 4.2 hank roving, and 36/1 yarn. To eliminate the effect of roll and spindle variations, the same roving and spinning spindles were used on cottons processed by the control and experimental lines. Similar precautions were taken to eliminate other factors that might contribute to experimental error.

A.S.T.M. procedures were followed in making waste, fiber, and yarn quality evaluations.

Discussion of Results

The results are presented in tabular form in terms of comparing the performance of the control and Opener-Cleaner processing lines, and of showing the performance of the Opener-Cleaner alone, with regard to per cent waste, cleaning efficiency, and lint loss. It should be kept in mind that these results are based on laboratory evaluations that are necessarily limited in scope, and therefore are considered only as indicative and not as conclusive.

Table II reveals that the two processing lines, and the Opener-Cleaner alone, have no significant effect on fiber length and length distribution. There is a slight lowering of fiber strength by the control line.

Information on cleaning effectiveness is presented by two methods in Table III. Mills usually consider the per cent waste removed, and on this basis it is seen that for the average of all cottons the Opener-Cleaner line removed 0.56% less waste and provided a slightly cleaner picker lap. Analysis of the waste by means of the Shirley Analyzer shows the Opener-Cleaner line had 8% more trash and 8% less lint in the waste, as compared with the control.

The second method of evaluation consists of determining the cleaning efficiency and lint loss. Shirley Analyzer determinations of the raw cotton and the picker lap show an average of 4% more cleaning and 0.4% less lint loss for the Opener-Cleaner line.

It is probable that these results would have been somewhat different if the Buckley and porcupine openers had been processing at their normal production rates, instead of 300 lb./hr.

At this point it is of interest to consider the processing performance of the Opener-Cleaner alone (Table IV). For the average of all cottons, about 2.5% waste was removed with 86% of the waste being foreign matter and 14% being lint. The cleaning efficiency was 35% and the lint loss 0.3%. Preliminary laboratory tests indicate that cleaning efficiency will decrease to about 28%, depending upon the cotton and trash characteristics, if the production rate is increased to 3000 lb./hr.

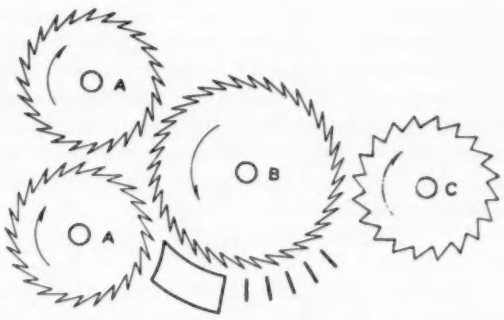


Fig. 5. Opener-Cleaner cylinders: (A) opening, (B) cleaning, and (C) doffing.

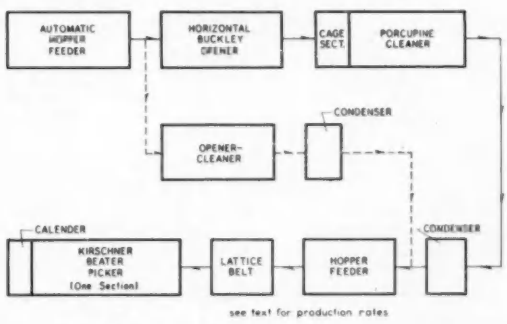


Fig. 6. Control and Opener-Cleaner processing lines.

To return to the processing lines, there is no appreciable difference in card waste and 1 nep per grain difference in neps for the average of all cottons (Table V).

All cottons behaved normally in processing through drawing, roving, and spinning. The strength, strength uniformity and elongation of the yarns from both lines are presented in Table VI. No significant differences are seen. Skein strength was also measured; the results followed the same trend as with single strand strength and therefore are not presented.

The yarn grade and long- and short-term uniformity are essentially equal for the control and Opener-Cleaner lines (Table VII).

An analysis of variance was made to determine the significance of difference of the results presented in the foregoing tables. Taking into consideration the magnitude of the interactions, the analysis showed a highly significant difference in cleaning efficiency and lint loss between the control and Opener-Cleaner lines. No other significant effects were revealed.

Summary

Originally planned as a system using three types of machines, the SRRL integrated cleaning system

TABLE II. Effect of Control and Opener-Cleaner Lines, and of the Opener-Cleaner, on Fiber Length and Strength of Five Cottons

Processing stage	Length[1] UQL, in.	ML, in.	CV, %	Strength[2] (1000 p.s.i.)
Acala 4–42				
Raw cotton	1.20	1.01	27	87.7
Control line lap	1.19	.98	30	85.6
Opener-Cleaner line lap	1.18	.97	30	86.1
After Opener-Cleaner	1.18	.98	29	88.0
Wilds				
Raw cotton	1.41	1.16	31	86.1
Control line lap	1.39	1.12	33	83.0
Opener-Cleaner line lap	1.38	1.11	33	87.6
After Opener-Cleaner	1.39	1.13	33	85.8
Deltapine 15				
Raw cotton	1.20	1.01	28	72.8
Control line lap	1.22	1.02	28	72.5
Opener-Cleaner line lap	1.20	.99	30	73.5
After Opener-Cleaner	1.19	.99	31	74.6
Unknown				
Raw cotton	1.08	.88	32	87.5
Control line lap	1.05	.82	36	84.7
Opener-Cleaner line lap	1.06	.85	34	86.8
After Opener-Cleaner	1.07	.85	34	87.4
Bobshaw				
Raw cotton	1.13	.97	24	92.0
Control line lap	1.10	.94	25	92.0
Opener-Cleaner line lap	1.11	.94	27	92.0
After Opener-Cleaner	1.11	.93	27	93.5
Average—All Cottons				
Raw cotton	1.20	1.01	28.2	85.2
Control line lap	1.19	.98	30.4	83.6
Opener-Cleaner line lap	1.19	.97	31.0	85.2
After Opener-Cleaner	1.19	.98	30.6	85.8

[1] Suter-Webb fiber array.
[2] Pressley, "0" gauge.

TABLE III. Effect of Control and Opener-Cleaner Lines on Waste, Cleaning, and Lint Loss

Processing line	Opening-picking waste, %	Trash in waste, %	Lint in waste, %	Cleaning efficiency, %	Lint loss, %	Trash in lap, %
Acala 4–42						
Control	1.89	50.2	49.8	28.1	0.94	2.3
Opener-Cleaner	1.31	73.5	26.5	27.5	0.35	2.4
Wilds						
Control[1]	1.62	80.9	19.1	32.3	0.31	2.4
Opener-Cleaner	1.53	79.3	20.7	37.4	0.32	2.2
Deltapine 15						
Control[1]	2.19	84.8	15.2	25.1	0.33	5.2
Opener-Cleaner	2.80	87.6	12.4	37.3	0.35	4.3
Unknown						
Control	6.92	77.6	22.4	54.8	1.55	4.6
Opener-Cleaner	5.07	87.2	12.8	50.0	0.65	5.0
Bobshaw						
Control	6.39	82.3	17.7	52.3	1.14	4.9
Opener-Cleaner	5.47	88.1	11.9	59.0	0.64	4.0
Average—All Cottons						
Control	3.80	75.2	24.8	38.5	0.85	3.9
Opener-Cleaner	3.24	83.2	16.8	42.2	0.46	3.6

[1] Buckley opener operated at low beater speed.

TABLE IV. Processing Performance of the Opener-Cleaner[1]

Waste removed, %	Trash in waste, %	Lint in waste, %	Cleaning efficiency, %	Lint loss, %
Acala 4–42				
0.94	76.7	23.3	23.8	0.22
Wilds				
1.11	85.9	14.1	31.7	0.16
Deltapine 15				
2.13	89.4	10.6	25.0	0.22
Unknown				
4.22	88.4	11.6	37.9	0.49
Bobshaw				
4.37	88.1	11.9	43.2	0.52
Average—All Cottons				
2.56	85.7	14.3	35.4	0.32

[1] 1500 lb./hr. production rate.

TABLE V. Effect of Control and Opener-Cleaner Lines on Card Waste and Neps[1]

Processing line	Strips, %	Motes, fly, and sweepings, %	Total waste, %	Neps, per grain
		Acala 4–42		
Control	3.87	1.82	5.69	15.8
Opener-Cleaner	4.31	1.53	5.84	14.6
		Wilds		
Control	4.82	1.93	6.75	9.7
Opener-Cleaner	4.98	1.88	6.86	12.9
		Deltapine 15		
Control	4.24	3.66	7.90	20.4
Opener-Cleaner	4.78	3.07	7.85	18.4
		Unknown		
Control	4.14	3.35	7.49	17.2
Opener-Cleaner	4.49	3.55	8.04	22.4
		Bobshaw		
Control	3.76	3.77	7.53	2.2
Opener-Cleaner	3.77	3.05	6.82	2.7
		Average—All Cottons		
Control	4.17	2.91	7.07	13.1
Opener-Cleaner	4.47	2.61	7.08	14.2

[1] Wilds cotton carded at 5 lb./hr., others at 10 lb./hr.

TABLE VI. Effect of Control and Opener-Cleaner Lines on Single Strand Strength, Strength Uniformity, and Elongation of 36/1 Yarn

Processing line	Yarn number × single strand str., oz.	Coef. of variation, %	Elongation, %
	Acala 4–42		
Control	292	11.6	6.8
Opener-Cleaner	283	12.5	6.5
	Wilds		
Control	286	11.5	6.4
Opener-Cleaner	288	10.6	6.5
	Deltapine 15		
Control	273	10.6	7.7
Opener-Cleaner	265	11.4	7.5
	Unknown		
Control	220	14.1	5.6
Opener-Cleaner	226	14.1	5.8

for textile mills is now comprised of an Opener-Cleaner as the only cleaning machine in the opening room and a Carding Cleaner as the only cleaning machine in the picking line.

Laboratory evaluations were made of a line of conventional mill opening-picking equipment and an experimental line wherein the Opener-Cleaner was substituted for a Buckley-type opener and a porcupine cleaner in the conventional line. The results indicated slightly higher cleaning efficiency and considerably lower loss of lint for the experimental line.

TABLE VI. (Cont.)

	Bobshaw		
Control	275	12.5	5.2
Opener-Cleaner	279	11.9	5.3
	Average—All Cottons		
Control	269	12.1	6.3
Opener-Cleaner	268	12.1	6.3

TABLE VII. Effect of Control and Opener-Cleaner Lines on the Grade and Uniformity of 36/1 Yarn

Processing line	Yarn grade	Uniformity[1] Coef. of variation, % 4 y.p.m.	50 y.p.m.
	Acala 4–42		
Control	C+	16.6	17.1
Opener-Cleaner	C+	16.3	16.5
	Wilds		
Control	B	16.8	15.9
Opener-Cleaner	B−	16.5	15.6
	Deltapine 15		
Control	B−	15.6	16.0
Opener-Cleaner	B−	15.9	15.8
	Unknown Variety		
Control	C	17.1	17.6
Opener-Cleaner	C+	17.4	17.2
	Bobshaw		
Control	B+	16.4	16.3
Opener-Cleaner	A−	17.0	16.3
	Average—All Cottons		
Control	B−	16.6	16.6
Opener-Cleaner	B−	16.6	16.3

[1] Uster Yarn Evenness Tester with Quadratic Integrator.

The Opener-Cleaner alone averaged 35% cleaning efficiency and 0.3% lint loss at a production rate of 1500 lb./hr. Cleaning efficiency ranged from 24% for a low trash content cotton to 43% for a high trash content cotton. Lint loss ranged from 0.22 to 0.52%.

The new Opener-Cleaner appears to hold promise as an effective means of opening, blending, and cleaning cotton, either as a component of the SRRL integrated cleaning system or for installation in connection with existing equipment.

It is planned to evaluate thoroughly the Opener-Cleaner and the integrated system under mill conditions as soon as practical.

Acknowledgment

The services of Mr. J. J. Brown and associates for processing the cottons into yarns, Miss Annie B. Cooper, Miss Dorothy C. Legendre and Mr. W. F. McSherry for the fiber and yarn evaluations, and Mr. H. W. Little and G. L. Louis for the statistical analysis of the data are gratefully acknowledged.

Literature Cited

1. Rusca, R. A., *Textile Inds.* **120**, No. 1, 108–109 (Jan. 1956); *America's Textile Reptr.* **70**, No. 5, 11–13 (Feb. 2, 1956).
2. Rusca, R. A., and Young, R. C., *Textile Inds.* **115**, No. 5, 107–111 (May 1951).
3. Rusca, R. A., and Young, R. C., *Textile Inds.* **117**, No. 7, 87–90 (July 1953).

The SRRL Integrated System for Opening and Cleaning Cotton—the Carding Cleaner and the Integrated Unit[1]

George J. Kyame and William A. Latour

Southern Regional Research Laboratory,[2] New Orleans, La.

Abstract

The changes made in a conventional one-process picker to convert the unit into a commercial size Carding Cleaner are described. The results of pilot scale tests of the machine in an experimental line are compared with those of a control line composed of conventional textile mill equipment. The data presented show that the carding cleaner line achieved an average cleaning efficiency of about 59% at a production rate of 435 lb./hr., as compared with the control line which achieved 35% cleaning at 356 lb./hr. Lint losses are $\frac{1}{3}$ to $\frac{1}{2}$ of those observed in the control line.

Also presented are data obtained in preliminary tests of a tentative integrated cleaning system comprised of the SRRL Opener-Cleaner and the SRRL Carding Cleaner. Nearly 82% cleaning with a lint loss of 0.70% was achieved in the integrated system as compared with 52% cleaning and 1.14% lint loss for the control line.

Introduction

One of the two cleaning machines in the SRRL Integrated Cleaning System is a high efficiency, medium production unit called the Carding Cleaner. Earlier research with an experimental carding cleaner had shown that cleaning efficiences of about 70% at 400 lb./hr. production could be achieved without damage to the cotton [1]. The principles of the new cleaner seemed to be best suited for incorporation in the finishing picker stage of textile mill operations. Consequently, a one-process picker was converted to Carding Cleaner operation for testing on a pilot scale.

The Carding Cleaner Line

The finisher section of the picker was first stripped of its Kirschner beater, evener pedals, feed rolls, damper box, and fan. These were replaced, as may be seen schematically in Figure 1, with a toothed cylinder, an anti-pluck feed roll with its associated guide bar, an air-blast doffer and fan, and a modified cage housing and beater cover.

The original feed roll drive system was modified by replacing the conventional cone drive with a wide-range variable speed pulley to drive the anti-pluck feed roll. Manual adjustment of the variable speed pulley controlled the speed of the anti-pluck feed roll, and this, in turn, determined the weight of the lap produced.

The Carding Cleaner line used in the tests included, in addition to the units shown in Figure 1, a Whitin Model K feeder used to pre-open the baled cotton prior to processing.

Test Procedure

Pilot scale tests were conducted to compare the Carding Cleaner with conventional mill equipment for cleaning efficiency, lint loss, fiber damage, neps, yarn strength, and yarn uniformity. Figure 2 shows the treatment given the cotton from the bale to the yarn. In the control line, the cotton was fed from a hopper to a horizontal Buckley opener, a porcupine cleaner, another hopper, and finally, twice through a picker section equipped with a Kirschner

[1] Presented by George J. Kyame at the 8th Cotton Research Clinic held at Savannah, Georgia, February 27–March 1, 1957.

[2] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture.

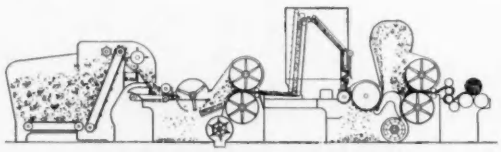


Fig. 1. The Carding Cleaner line.

carding beater. In the experimental line, the cotton was put through two hoppers in succession, a breaker picker, and the Carding Cleaner. The laps from both lines were then carded into 55-grain sliver. Except for the Wilds variety, all cottons were carded at 10 lb./hr.; the Wilds was carded at 5 lb./hr. Nep counts were taken at the end of the twentieth pound of cotton processed in each case.

The card sliver was drawn twice and then processed into 4.2 hank roving. The roving was spun into 36/1 yarn which was graded and tested for strength and uniformity.

Trash content determinations, Suter-Webb fiber arrays and Pressley strength tests were made on samples of cotton taken at four points in the above-mentioned series of operations, viz., from the bale, from the finisher picker lap of the control line, and from the breaker picker bat and Carding Cleaner lap of the experimental line.

The tests were carried out with five popular varieties of cotton which differed in staple length and trash content. These, along with pertinent physical properties, are listed in Table I of the paper on the Opener-Cleaner, by Rusca and Young in this issue. The Bobshaw cotton, also listed in the table, was used to test the integrated system which will be described later. Three replicate tests were made with each of the five cottons so that the data would have some measure of statistical significance.

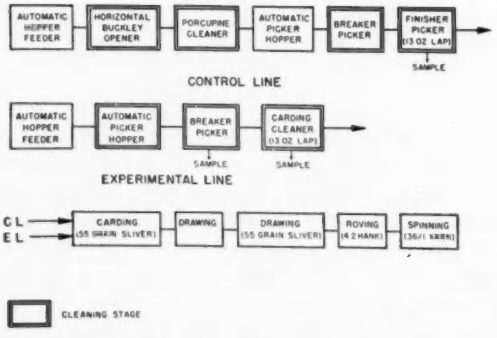


Fig. 2. Processing lines used in the tests.

Discussion of Results

The effect of the Carding Cleaner line on cleaning efficiency and lint loss is seen in Table I. For all

TABLE I. Effect of the Carding Cleaner Line on Cleaning Efficiency, Lint Loss, and Waste Removed

Processing line	Cleaning efficiency, %	Lint loss, %	Waste removed, %	Lint in waste, %	Rate of production, lb./hr.
		Acala 4–42			
Control	28.1	0.94	1.89	49.8	347
Carding Cleaner	53.8	0.24	1.74	13.7	408
		Wilds			
Control	32.3	0.31	1.62	19.1	367
Carding Cleaner	63.6	0.30	2.43	12.4	468
		Coker 100 W.R.			
Control	34.6	1.00	2.78	36.0	361
Carding Cleaner	53.3	0.30	2.50	12.1	418
		Deltapine 15			
Control	25.1	0.33	2.19	15.2	357
Carding Cleaner	57.8	0.34	4.64	7.3	438
		Unknown			
Control	54.8	1.55	6.92	22.4	350
Carding Cleaner	64.7	0.71	6.67	10.7	445
		Average			
Control	35.0	0.83	3.08	28.5	356
Carding Cleaner	58.6	0.38	3.60	11.2	435

Note: Horizontal Buckley Opener Beater speeds were as follows: Wilds cotton, 320 r.p.m.; Deltapine cotton, 392 r.p.m.; and remaining cottons, 540 r.p.m.

TABLE IA. Cleaning Efficiency, Lint Loss, and Waste Removed in the Carding Cleaner Unit

Variety of cotton	Cleaning efficiency, %	Lint loss, %	Waste removed, %	Lint in waste, %	Rate of production, lb./hr.
Acala 4–42	47.7	0.08	1.30	6.5	408
Wilds	52.3	0.14	1.60	9.1	468
Coker 100 W.R.	43.9	0.12	1.82	6.9	418
Deltapine 15	53.8	0.19	3.83	5.1	438
Unknown	55.2	0.38	4.52	8.8	445
Average	50.6	0.18	2.61	7.3	435

cotton varieties tested, the amount of cleaning accomplished in the experimental line is significantly greater than that achieved in the control, line. In the case of the Deltapine cotton, the difference in cleaning rates between the two lines would have been less pronounced had the speed of the horizontal Buckley beater been the same as was used for the other cottons of comparable staple length, but, in all probablity, the increase in cleaning would have been offset by higher lint loss. Lint losses, in general, are lower in the Carding Cleaner line. The combined effect of the higher cleaning efficiency and lower lint loss of the experimental line is seen in the figures for the lint content of the waste. These range from about $\frac{1}{3}$ to $\frac{1}{2}$ the corresponding lint contents of the control line waste.

The contribution of the Carding Cleaner to the experimental processing line is indicated in Table I A. The data presented are based on the quantity and trash content of the cotton emerging from the breaker picker, and not that of the raw stock—the basis for the data given in the previous table. The figures show an average cleaning efficiency, for the five cottons, of 50.6% at 435 lb./hr. production with only 0.18% lint loss.

The cleaning efficiencies obtained, do not duplicate those reported for the experimental machine, but this is believed due to the feeding method used. It will be recalled that the "anti-pluck" feed roll was designed to advance a thin layer of cotton at a rapid rate to the cleaning cylinder [1]. This condition was not met in the present tests. Instead, the breaker

TABLE II. Effect of the Carding Cleaner Line on Neps and Card Waste [1]

Processing line	Neps[2] per grain	Card waste		
		Strips, %	Motes and fly, %	Total, %
Acala 4–42				
Control	15.8	3.87	1.51	5.70
Carding Cleaner	14.3	3.17	1.24	4.71
Wilds				
Control	9.7	4.82	1.71	6.74
Carding Cleaner	11.6	4.40	1.07	5.70
Coker 100 W.R.				
Control	20.9	4.54	1.85	6.72
Carding Cleaner	21.7	4.23	1.44	5.94
Deltapine 15				
Control	20.2	4.24	3.34	7.90
Carding Cleaner	19.1	3.84	1.70	5.86
Unknown				
Control	20.3	4.14	3.12	7.49
Carding Cleaner	17.2	3.81	2.33	6.28
Average				
Control	17.4	4.32	2.31	6.91
Carding Cleaner	16.8	3.89	1.56	5.70

[1] Wilds cotton carded at 5 lb./hr.; other cottons carded at 10 lb./hr.
[2] Nep counts were taken after carding 20 lb. of cotton.

TABLE III. Effect of the Carding Cleaner Line on Fiber Length Distribution and Strength

Sample	Length distribution[1]			Tensile[2] strength (1,000 p.s.i.)
	UQL, in.	ML, in.	CV, %	
Acala 4–42				
Raw stock	1.19	0.98	30	84.3
After control line	1.19	0.98	30	85.5
Before Carding Cleaner	1.19	0.99	29	87.0
After Carding Cleaner	1.19	0.98	30	83.9
Wilds				
Raw stock	1.40	1.14	32	82.3
After control line	1.36	1.09	35	83.3
Before Carding Cleaner	1.38	1.12	34	83.3
After Carding Cleaner	1.36	1.10	34	83.1
Coker 100 W.R.				
Raw stock	1.20	0.97	33	72.2
After control line	1.18	0.95	33	72.1
Before Carding Cleaner	1.18	0.94	34	72.0
After Carding Cleaner	1.17	0.93	33	72.8
Deltapine 15				
Raw stock	1.22	1.02	28	72.1
After control line	1.22	1.02	28	72.4
Before Carding Cleaner	1.23	1.04	27	71.2
After Carding Cleaner	1.22	1.01	29	73.1
Unknown				
Raw stock	1.06	0.85	33	87.6
After control line	1.05	0.82	36	84.5
Before Carding Cleaner	1.04	0.83	34	87.1
After Carding Cleaner	1.04	0.81	36	87.8
Average				
Raw stock	1.21	0.99	31.2	79.7
After control line	1.20	0.97	32.4	79.6
Before Carding Cleaner	1.20	0.98	31.6	80.1
After Carding Cleaner	1.20	0.97	32.4	80.1

[1] Suter-Webb fiber array.
[2] Pressley; "0"-gauge.

bat, which ranged from 3 to 5 in. thick, was fed at a slow rate in the same manner as in conventional feed systems, thus decreasing the effectiveness of the anti-pluck feed roll. Research now under way is directed toward correcting this fault without curtailing the capacity of the machine.

Table II shows no significant differences in the number of neps produced at the card. Examination of the card waste data in the table reveals less motes and fly extracted from the carding cleaner laps. This is to be expected since more of the motes present in the raw stock are removed in the cleaning operation. However, there is also observed a reduction in the amount of card strips. These savings in card strips range from 0.3 to 0.7% of the weight of the cotton processed. No explanation for this behavior is offered.

The fiber array and strength data given in Table III indicate no damage to the cotton. The small differences observed had no effect on the quality of the yarns. This is borne out by the data in Table IV which show no significant differences in yarn strength, either single strand or skein, strength uniformity, or elongation.

In Table V, no effect on yarn grade is noted. Yarn uniformity, however, shows a slight, but statistically significant improvement. Short term variations in yarns made from cottons processed in the Carding Cleaner line averaged 0.3% less than the variations in the control yarns; the long term variations were 0.5% less.

Table VI summarizes the results of the tests. Shown in the table are the over-all averages of the 15 data items obtained from the three replicate tests with each of the five cottons. Significant differences between processing lines are identified for two levels of probability, 95 and 99%. Differences in cleaning efficiency, lint in waste, lint loss, total card waste, card strips, and yarn uniformity are all significant, and are in favor of the Carding Cleaner line. The difference in waste removed, while also significant, is somewhat in doubt because the variance due to interaction was significant to the same degree. No significant differences are observed for neps, fiber

TABLE IV. Effect of the Carding Cleaner Line on Yarn Strength, Strength Uniformity, and Elongation of 36/1 Yarn

	Single strand			Skein	
Processing line	Yarn number ×single strand str., oz.	Coefficient of variation, %	Elongation, %	Yarn number ×skein str., lb.	Coefficient of variation, %
		Acala 4–42			
Control	292	11.6	6.8	2226	4.3
Carding Cleaner	292	12.1	6.8	2248	4.0
		Wilds			
Control	286	11.5	6.4	2289	3.5
Carding Cleaner	286	12.2	6.6	2295	5.2
		Coker 100 W.R.			
Control	236	11.1	6.8	1786	4.4
Carding Cleaner	237	12.2	6.9	1795	4.2
		Deltapine 15			
Control	273	10.6	7.7	2095	4.6
Carding Cleaner	282	10.9	7.5	2126	5.2
		Unknown			
Control	226	14.1	5.8	1663	5.3
Carding Cleaner	229	12.7	6.0	1687	5.5
		Average			
Control	263	11.8	6.7	2012	4.4
Carding Cleaner	265	12.0	6.7	2030	4.8

TABLE V. Effect of the Carding Cleaner Line on the Grade and Uniformity of 36/1 Yarn

Processing line	Grade	Coefficient of variation at 4 y.p.m., %	Coefficient of variation at 50 y.p.m., %
	Acala 4–42		
Control	C+	16.6	17.1
Carding Cleaner	C+	16.6	16.7
	Wilds		
Control	B	16.8	15.9
Carding Cleaner	B	16.4	15.5
	Coker 100 W.R.		
Control	C−	17.2	17.7
Carding Cleaner	C−	16.6	17.1
	Deltapine 15		
Control	B−	15.6	16.0
Carding Cleaner	C+	15.1	15.5
	Unknown		
Control	C	17.1	17.6
Carding Cleaner	C	17.2	17.3
	Average		
Control	C+	16.7	16.9
Carding Cleaner	C+	16.4	16.4

strength, upper quartile length, mean length, fiber length variability, yarn strength, and yarn elongation.

The Integrated System

A preliminary test was made to determine the effectiveness of the proposed integrated system [2] for cleaning cotton. The Bobshaw cotton was processed in a cleaning line consisting of a hopper, the Opener-Cleaner, another hopper, a breaker picker, and the Carding Cleaner. Three replicate tests were made. The results were then compared with the data obtained for the control line. The results are summarized in Table VII.

The cleaning efficiency of 81.5% obtained in the integrated system is about 56% higher than the cleaning achieved in the control line. The figures for "Waste removed" do not reflect the big difference observed in the cleaning efficiency data, because they include the lint losses which are nearly 40% lower in the integrated system than they are in the control line. The "Lint in waste" and "Lint loss" figures emphasize the high trash removal–low lint loss features of the integrated system.

Nep counts show an unfavorable increase in the

TABLE VI. Summary and Statistical Significance of the Results

Processing line	Cleaning efficiency, %	Waste removed, %	Lint in waste, %	Lint loss, %
Control	35.0	3.08	28.5	0.83
Carding cleaner	58.6***	3.60***†	11.2***	0.38***
	Neps (number per grain)	Total card waste, %	Card strips, %	Fiber strength (1,000 lb./sq. in.)
Control	17.4	6.91	4.32	79.6
Carding cleaner	16.8	5.70***	3.89***	80.1
	Upper quartile length, in.	Mean length, in.	Fiber length CV, %	Yarn number ×skein str., lb.
Control	1.20	0.97	32.4	2012
Carding cleaner	1.20	0.97	32.4	2030
	Yarn number ×single strand str., oz.	Yarn elongation, %	Yarn uniformity Uster at 4 y.p.m., % CV	Yarn uniformity Uster at 50 y.p.m., % CV
Control	263	6.7	16.7	16.9
Carding cleaner	265	6.7	16.4*	16.4***

* *** † See Table VII.

TABLE VII. Effect of the Integrated System on Processing and Properties of Bobshaw Cotton

Processing line	Cleaning efficiency, %	Waste removed, %	Lint in waste, %	Lint loss, %
Control	52.3	6.39	17.9	1.14
Integrated	81.5**	7.54*	9.3**	0.70**
	Neps (number per grain)	Total card waste, %	Card strips, %	Fiber strength (1,000 lb./sq. in.)
Control	2.2	7.53	3.73	104.1
Integrated	4.3**	4.77**	3.38	99.0*
	Upper quartile length, in.	Mean length, in.	Fiber length CV, %	Yarn number ×skein str., lb.
Control	1.10	0.94	25	2122
Integrated	1.10	0.94	26	2144
	Yarn number ×single strand str., oz.	Yarn elongation, %	Yarn uniformity Uster at 4 y.p.m., % CV	Yarn uniformity Uster at 50 y.p.m., % CV
Control	275	5.2	16.4	16.3
Integrated	282*	5.4	16.4	16.3

* Significant at the 95% level of probability.
** Significant at the 98% level of probability.
*** Significant at the 99% level of probability.
† Interaction also significant to the same degree.

integrated system; future research will be directed toward determining the cause and its remedy. Total card waste is significantly lower for the cotton processed in the integrated system; this is to be expected in view of the cleaner cotton delivered to the card. Card strips are also lower but not significantly so. No significant effect was noted on fiber or yarn properties.

Conclusion

In conclusion, it may be said that the pilot scale Carding Cleaner looks promising. A mean cleaning efficiency of about 59% with low lint loss has been achieved in an experimental line operating at an average production rate of 435 lb./hr., with no damage to the fiber. Some improvement in product quality is also noted. Research now under way should increase the cleaning efficiency of the Carding Cleaner and improve the uniformity of the laps produced.

The SRRL Carding Cleaner, working in conjunction with the SRRL Opener-Cleaner in an integrated system, permits the achievement of an unusually high cleaning efficiency with no damage to the cotton except for an increase in neps. This conclusion is based on limited pilot scale tests.

Acknowledgment

The authors wish to thank their former co-worker, Mr. Norman P. Sommers, who participated in the latter phases of this research and made the numerous trash content determinations. They are indebted also to Messrs. J. J. Brown for planning and directing the processing operations, G. L. Louis for making the nep counts, and H. W. Little for his statistical analysis of the data.

The authors also wish to express their sincere appreciation of the work done by Misses A. B. Cooper and D. C. Legendre in performing the fiber tests, and Mr. W. F. McSherry, who made the yarn tests.

Literature Cited

1. Kyame, G. J., and Mayer, M., Jr., TEXTILE RESEARCH JOURNAL **25**, 476–480 (1955).
2. Rusca, R. A., *Textile Inds.* **120**, No. 1, 108–109 (Jan. 1956).

Fiber Strength as a Function of Fiber Length and Gauge Length[1]

K. L. Hertel

Agricultural Experiment Station, The University of Tennessee, Knoxville, Tenn.

1. Introduction

The cotton industry over the years has found that staple length and skein strength are representative measurable properties of its raw material and finished products, respectively. The economic factor restricts the number of properties to be measured, and since one is the smallest number, industry has selected the one in each case that most universally represents quality in fiber on the one hand and quality in yarn on the other. These decisions do not mean necessarily that fiber length is the most important fiber property or that skein strength is the most important yarn property. They do serve as starting points for detailed investigations. Since fiber length, fineness, and strength in general tend to vary together and also with yarn strength, it is obvious why the relative importance of each of the fiber properties is unclear. It is also obvious why the one property of the three that is readily visible and measurable is given so much credit for yarn strength. In fact, it would seem impossible from qualitative evidence to show their relative importance and difficult with statistical data because of their mutual correlations. There are other approaches, however, that are more revealing. The mutual correlations can be modified by cutting fibers to various lengths or by using man-made fibers in which only length or fineness is varied. A theoretical examination is also helpful. Sullivan [3] investigated the contribution of fiber length, fineness, friction, and strength in producing strength of some idealized yarn structures. From his study it appears that fiber strength is relatively more important than length and fineness for producing yarn strength. It is the particular object of this paper to examine fiber strength as a function of fiber length and gauge length.

2. Fiber Tenacity versus Fiber Length

It is generally agreed that cottons of long staple tend to be stronger than those of short staple. In Figure 1 the fiber tenacity at $\frac{1}{8}$-in. gauge for the 1954 Annual Variety and Environmental Study Cottons is plotted against the upper half mean length. The over-all relation between skein strength and fiber length has been given by Sheldon. (See Textile handbook, such as *Textile World Fact File*, p. 29, 1956.) The skein strength computed for 22's

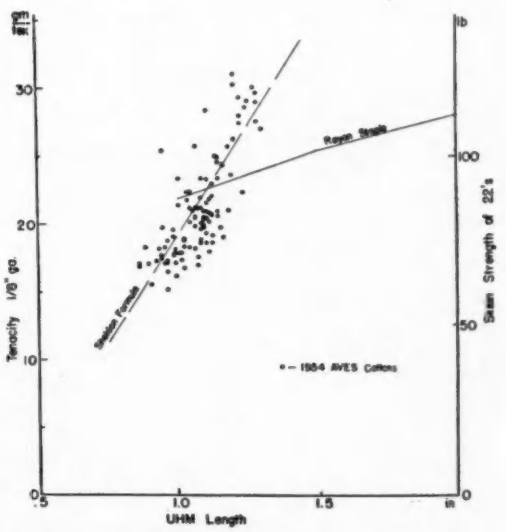


Fig. 1. Tenacity at $\frac{1}{8}$-in. gauge versus upper half mean length of 1954 Annual Variety and Environmental Study Cottons of the U.S.D.A. Cotton Branch combined with yarn strength of 20's versus rayon staple length and yarn strength of 22's versus cotton staple length as predicted by the Sheldon formula.

[1] This paper was presented at the 1957 National Cotton Council Clinic, Savannah, Ga. This work was supported in part by Regional Research Funds provided by the Hatch Act and administered by the S-1 Committee.

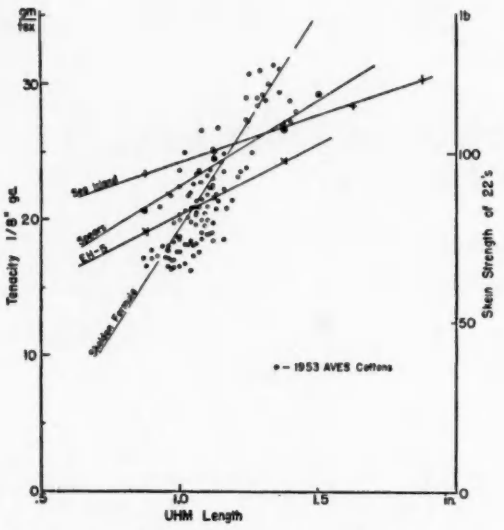


Fig. 2. Tenacity at $\frac{1}{8}$-in. gauge versus upper half mean length of 1953 Annual Variety and Environmental Study Cottons of the U.S.D.A. Cotton Branch combined with tenacity at $\frac{1}{8}$-in. gauge length of sorted fiber lengths versus fiber length and yarn strength of 22's versus cotton staple length as predicted by the Sheldon formula.

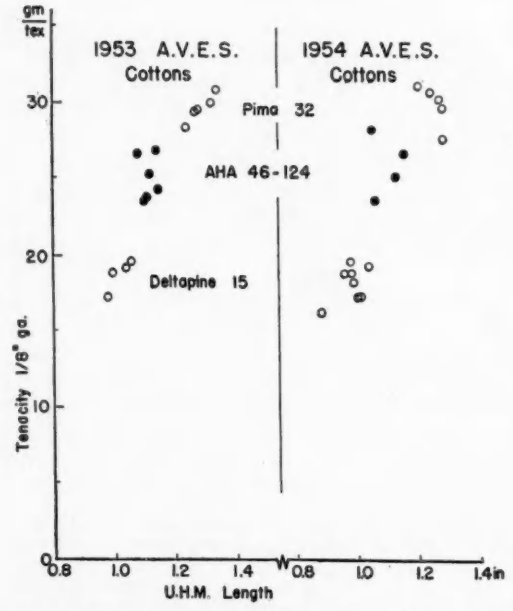


Fig. 3. Tenacity at $\frac{1}{8}$-in. gauge of 1953 and 1954 Annual Variety and Environmental Study Cottons of the U.S.D.A. Cotton Branch for selected cottons grown at four or more locations versus upper half mean length.

yarn is shown in the figure as a dashed line labeled Sheldon formula. Also the relation of skein strength for 20's rayon staple [2] is plotted against fiber length. In rayon, presumably, all properties remain constant while length alone varies. The slope of the rayon staple line thus shows how the length of fiber changes yarn strength. The much larger slope of the Sheldon formula gives the total change in yarn strength due to changes in fiber length, strength, fineness, and other properties that are correlated with fiber length. From the agreement between the trend in the fiber tenacity and the Sheldon formula, it might be thought that the increase in yarn strength was due wholly to the increase in fiber strength, but this is not true. Fiber length and fineness do influence yarn strength. The 1953 Annual Variety and Environmental Study Cottons are shown in Figure 2 with the rayon relation replaced by the relationships of fiber strength or tenacity to fiber length in the cases of three cottons. The Sea Island was taken from a sample of card sliver while Spears and EH-5 were taken from saw-ginned samples. Previous preliminary studies had shown no significant difference among hand-, roller- and saw-ginned samples of the same cottons. The cottons were sorted on a Suter-Webb sorter into $\frac{1}{4}$-in. length interval components.

There are two features of these results that are of particular interest. The slope of the Sheldon formula line is about the same as the general trend among the Annual Variety and Environmental Study Cottons as a whole, whereas the slopes within the three cottons is much less. Also the slopes within the three cottons are near that for rayon yarn. There is a suggestion, therefore, that there may be some length element within the fiber that is analogous to the fiber length in yarn. The length of this element would seem to be directly proportional to the fiber length itself. Subsequent investigations were directed toward revealing the nature and size of such a length element.

Within a ginned or carded fiber population, both genetical and environmental differences between length components should be nil, and the effect of length alone should be revealed. If the change in tenacity with length is unaffected by environment, the same variety grown at different locations should show the small slope as that within a cotton. Three Annual Variety and Environmental Study varieties grown at four or more locations in both 1953 and

1954 are shown in Figure 3. No generalization within variety is suggested, but the familiar trend among the cottons is obvious.

3. Fiber Tenacity versus Gauge Length

Fiber tenacity in cotton fibers varies so markedly with gauge length that any significance which tenacity might have could be masked by the strong influence the gauge length selected has upon tenacity. The three cottons, therefore, were each sorted on the Suter-Webb sorter into length components and each component tested with the Stelometer at nominal gauge length of from 0 to $\frac{7}{32}$ in. in steps of $\frac{1}{32}$ in. These data are displayed in Figures 4, 5, and 6. The solid circles represent the average of tenacity for 4 to 8 breaks. The good regularity among the data from each cotton suggested further investigation into possible interrelationships.

4. Discussion of Results

In examining the data presented, it must be remembered that there are only three widely different cottons represented. Any conclusions about properties among the cottons must be very tentative and those within cottons taken with reservations. This paper is a report of the progress that has been made on an investigation still under way.

The first problem was to find a way of transforming the data so that they could be plotted to give an array of points that is approximately linear. It was readily found that log T (tenacity) plotted against log G (gauge length) for any one length component gave such an array. The slope of this array appears to be mainly associated with the cotton variety and its characteristic staple length but secondarily correlated with the length component within the cotton. Lines representing the arrays appeared to be displaced from one another in an orderly fashion and in step with length. Since neither inheritance nor environment varies within a cotton, the causative factor changing tenacity for a given gauge length must be correlated quite directly with fiber length. Several possibilities present themselves.

One possibility is that longer fibers are intrinsically stronger. If this is the primary cause of displacement, the several curves within a cotton could be brought into coincidence by merely adjusting the scale for tenacity. For example, in Figure 6 an expansion of the tenacity scale for each

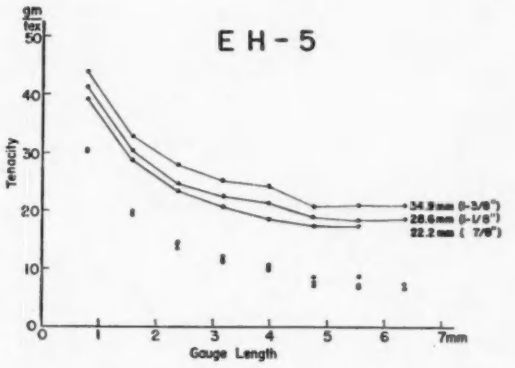


Fig. 4. Tenacity versus gauge length of sorted fiber lengths from EH-5 cotton.

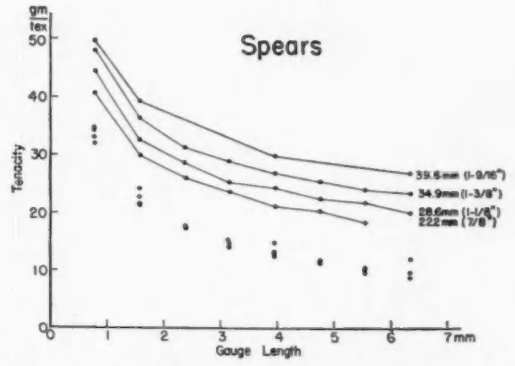


Fig. 5. Tenacity versus gauge length of sorted fiber lengths from Spears cotton.

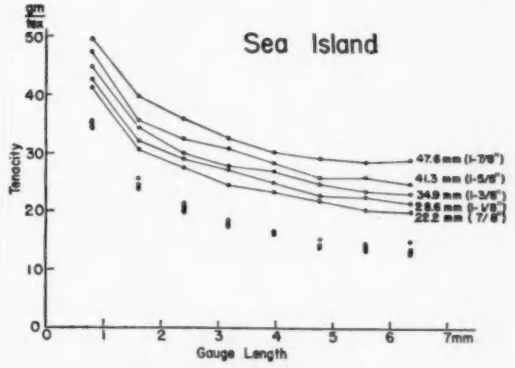


Fig. 6. Tenacity versus gauge length of sorted fiber lengths from Sea Island cotton.

length component to bring the values for the shortest gauge length into coincidence would be a percentagewise expansion that would leave the curves for the shorter lengths well below the longer length curves at the larger gauge lengths. The assumption, therefore, that the change in tenacity is primarily due to a change in the intrinsic strength of the cellulose is inconsistent with the data for all three cottons.

The curves appear to have nearly the same shape but merely displaced one above the other. A favorite concept in textiles is the application of the weakest link notion. If, then, one assumes the existence of a weakness pattern, genetically determined for a particular cotton, but modified by the change in fiber length, the pattern might change in intensity or in spacing or both as fiber length changes within that cotton. A proportionate reduction in the weaknesses with the potential strength remaining constant would be equivalent to raising the curves more at the long gauge lengths than at the short. This assumption too is inconsistent with the data. The proper combination of increase in intrinsic strength and simultaneous proportionate decrease in the magnitude of weakness with increase in fiber length would be equivalent to a vertical displacement of the curves. The open circles in Figures 4, 5, and 6 represent a displacement downward proportional to the length of the fiber. The decrease in scatter is encouraging although the demand for the simultaneous application of two assumptions, even though plausible, lacks elegance and will be passed by for the moment.

A more intriguing hypothesis assumes that the magnitude of the weaknesses remains constant while their spacings vary directly with the fiber length. Admittedly a more realistic and also a much more complicated assumption would encompass variations in both magnitude and spacing. For the present we shall pursue the simpler assumption that the spacing is proportional to the fiber length. If, then, fibers are tested at a gauge length proportional to the fiber length, the same number of weak places of the same magnitude should occur within the gauge length space. Fibers of different lengths within the same cotton should have the same

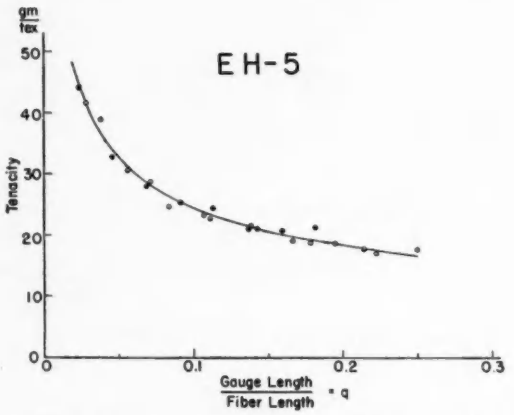


Fig. 7. Tenacity versus the ratio of gauge length to fiber length from EH-5 cotton with curve from equation $T = 47.5(5^s/50\,q)^s$. $s = 0.41$.

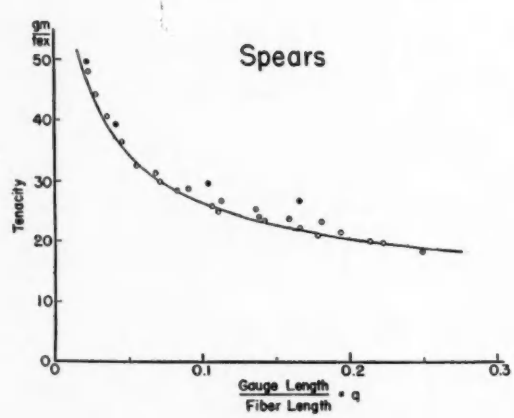


Fig. 8. Tenacity versus the ratio of gauge length to fiber length from Spears cotton. $s = 0.31$.

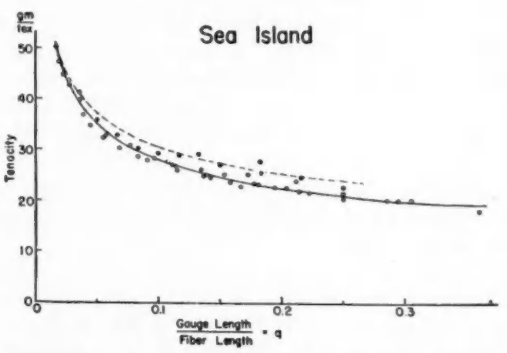


Fig. 9. Tenacity versus the ratio of gauge length to fiber length from Sea Island. $s = 0.32$ for solid lines, $s = 0.27$ for dashed line.

tenacity pattern if plotted against the ratio of gauge to fiber length rather than against gauge length alone. The data of the three cottons are plotted in Figures 7, 8, and 9. Although a single curve can be drawn through the array of points, a more critical examination reveals systematic variations among the data. The largest deviation occurs with the longest component and is represented by the solid circles in each case. Curves like those of Figures 7, 8, and 9 were first drawn in accordance with straight lines through the plot of log T versus log $1/q$ or log L/G, as in Figure 10, but still slight deviations were noted. Various modifications of the dimensionless quantity $1/q$ were tested in order to match the slight curvature and its variation with gauge length. One promising modification was the replacement of $1/q$ with $5^q/q$ and a second, by Kerr, in which $1/q$ is replaced with $1/q$ to the $1/(1+q)$ power, that is

$$\left(\frac{1}{q}\right)^{1/(1+q)}$$

Both modifications improved the linearity, but neither was without some slight imperfection. The solid and dashed curves in Figures 7, 8, and 9 eventually were drawn in accordance with the equation

$$T = 47.5(5^q/50q)^s \qquad (1)$$

where s is the slope of the best line through the data plotted as log T versus log $5^q/50q$, and 47.5 is the average number given by the intercept on the log T axis. Each of these forms [$5^q/q$ and $(1/q)^{1/(1+q)}$] was carried through the same subsequent analysis and led essentially to the same conclusions. The interpretations, therefore, do not seem to depend critically upon the particular form of the empirical equation so long as it closely approximates the data, but instead depend more directly upon the underlying physical relationships existing among the data.

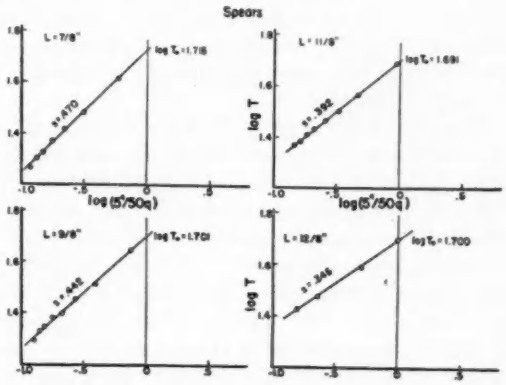


Fig. 11. Log tenacity versus log $(5^q/50\,q)$ for several fiber lengths from Spears cotton.

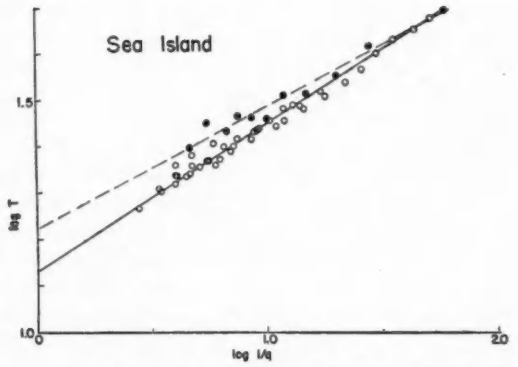


Fig. 10. Log tenacity versus log (fiber length/gauge length) from Sea Island. $s = 0.32$ for solid line, $s = 0.27$ for dashed line.

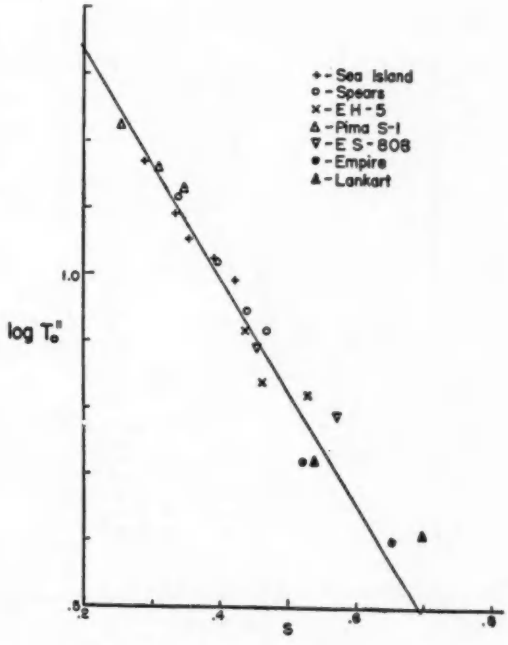


Fig. 12. Log T_0 versus s from equation $\log T_0 = s \log (5^q/q) + \log T_0$.

The "weakest link" theory of Peirce [1] gives little suggestion of the form for the equation. He investigated the dependence of yarn strength upon the specimen length. The theory should apply equally to fibers. In the present case, however, not only is the form of the frequency function not known but the absolute value of the specimen length or gauge length is unknown and, too, the data are based upon bundle strength rather than upon single fiber strength. The further discussion is therefore confined to the empirical equation in which $1/q$ is replaced by $5^q/50q$.

The data for the several length components of each of the three cottons exhibit the same general characteristics as Spears, shown in Figure 11. The linearity has been improved but there is still a residual change from short to long components. When $1/q$ was replaced by $(1/q)^{1/(1+q)}$, the linearity was better at long gauge lengths but not so good near zero gauge. At this stage of the investigation it appeared unprofitable to attempt to secure better empirical agreement but rather to recognize and tolerate the lack of it until a relationship based upon some physical reasoning can be evolved.

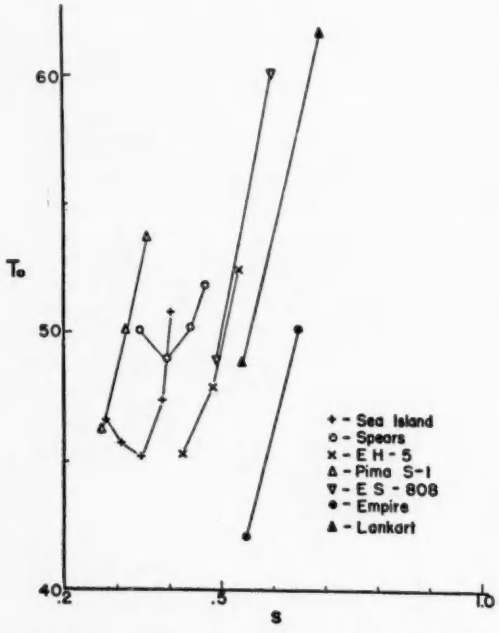


Fig. 13. Tenacity at nominal zero gauge length versus s.

The slopes and intercepts of the family of lines like those in Figure 11 appeared to be inversely related. The relationships turned out to be surprisingly good for Sea Island, Spears and EH-5, as shown with other cottons in Figure 12. Not only is there an approach to a linear trend but the trend is about the same for all three cottons. This is not true, however, of cottons tested later that are included in Figure 12. Even so, the line established for the first three cottons in probably the best line through the array of points for all seven cottons.

When Equation 1 is written as $T = T_0''(5^q/q)^s$, the straight line in Figure 12 has the equation $\log T_0'' = -s \log 50 + \log 47.5$. The points in Figure 12 came from plots of $\log T$ versus $\log 5^q/q$ similar to Figure 11, in which $\log T_0''$ for each length group of a cotton is the value of $\log T$ for the extension of the straight line to $\log 5^q/q = 0$. It would appear, therefore, that insofar as the data fit the curves, the tenacity of all seven cottons is represented by $T = 47.5(5^q/50q)^s$. This equation gives the tenacity in terms of the ratio of gauge to fiber length and the parameter s. In practice the effective gauge length is substantially constant and hence for a given fiber length the tenacity is given by the single parameter s. One may be willing to concede that a single factor is most important, but there must be additional parameters that influence tenacity.

It is noted that each of the three sets of points show a slight curvature concave to the right. The curvature can be enhanced by using $\log T_0$ and slope s from lines of $\log T$ versus $\log 5^q/50q$ instead of $\log 5^q/q$. The orderly array of points in Figure 12 is now converted to the scatter of Figure 13. It was noted, however, that Figure 13 became ordered if the points representing each cotton were translated so that the 9/8-in. points were brought into coincidence. The result is shown in Figure 14 along with a parabola fitted to the points. The equation of the parabola is $T_0/T_0' = 2.4 - 3.4\, s/s' + 2(s/s')^2$, where T_0' and s' are the values of T_0 and s for 9/8-in. fiber length. The dashed portion is the extrapolation of the parabola to the vertical axis that looks more plausible in Figure 15 where a substitution of variables converts the parabola into a straight line. The extrapolation is included because the value given has a plausible interpretation and a reasonable magnitude.

It will be recalled that the analysis presented

thus far is based on the assumption that within a boll the fibers have the same relative pattern of weak places. The spacing within the pattern is then directly proportional to the fiber length and would approach infinity as the length of the fiber approached infinity. On this same assumption, slope s would become zero for fibers of infinite length. The tenacity, therefore, would be uniform and a maximum because weak spots would be infinitely wide apart. Since $T_0/T_0' = 2.4$, this maximum tenacity would be about 2.4 times the present zero gauge tenacity. Using the same equation, the tenacity can be predicted for the gauge length equal to the fiber length for $q = 1$. This tenacity should be the average weakest point in the whole fiber. It turns out to have values of 0.73 T_0' to 0.20 T_0', depending upon the values of s. Similar quantities were obtained using $(1/q)^{1/(1+q)}$ instead of $5^q/q$, with the result that the maximum tenacity was 3.4 T_0' and the minimum ranged from 0.48 T_0' to 0.14T_0'.

The tenacities of very diverse cottons have been represented by the single relationship $T = T_0' r(5^q/50q)^s$ with four parameters, where $r = 2.4 - 3.4\, s/s' + 2(s/s')^2$. T_0' is a reference tenacity within a variety ($1\frac{1}{8}$-in. fiber at 0.0234-in. gauge) while s/s' and q are pure numbers. It seems likely, therefore, that tenacity in cotton is well determined by a few parameters or factors. This is not unreasonable, since the secondary wall is almost pure cellulose chains combined in a helix at about 30° with the axis. The cellulose molecules have regions of very high order of arrangement and others of a low order. The ultimate strength of the cellulose chain or oxygen "bridge" is a constant in all cottons. The parameters then are called upon only to represent the various types of disorder such as the angle the helix makes with the axis, the scatter about this angle, the distance between points of disorder, and the intensity of this disorder. A large portion of the cellulose in cotton is ordered. At reversals where the direction of the helix changes, there is a transition from one ordered region to another and this should be a region of much less order. Another type of disorder would result where two ordered regions join without reversal. The total order-disorder pattern may give rise to the weakness pattern referred to earlier. The parameter s may somehow represent a combination of all types of disorder. This could account for the fair agreement of Equation 1. The parameter r involves the ratio of the disorder represented by s for any fiber length to that represented by s' for a standard fiber length (9/8-in.). The parameter T_0' must involve the ultimate strength of the cellulose

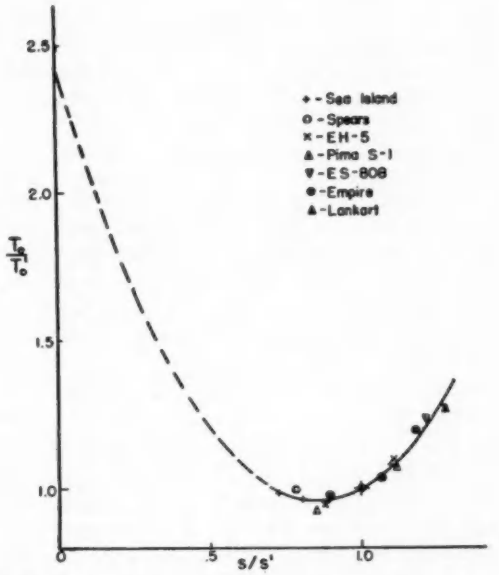


Fig. 14. T_0/T_0' versus s/s', where T_0' and s' are the values of T_0 and s, respectively, for $1\frac{1}{8}$-in. length group.

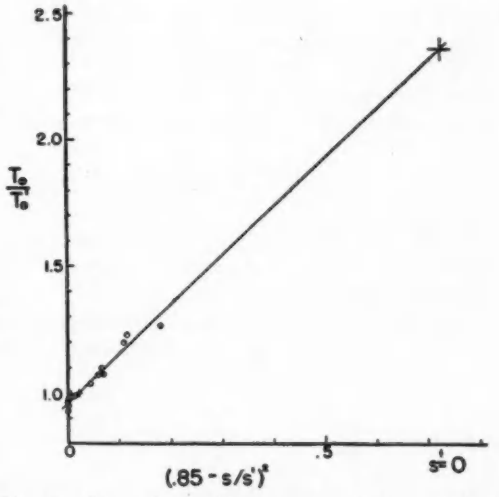


Fig. 15. Change in coordinates to convert the parabola of Figure 14 to a straight line.

chain modified by the chain length and the helix angle along with other types of disorder. The helix angle and some other types of disorder should be correlated with the X-ray angle. These possible relations between physical properties and the parameters are suggestive only. They point the direction for further investigation. If the empirical equation suggests new lines of approach to a better understanding of the cotton fiber, it will have served a good purpose. It should not be considered an end in itself.

5. Conclusions

This is a progress report and hence the conclusions are only tentative. The data, however, on those cottons studied were very consistent and had little scatter. Also, the conclusions drawn from the first three cottons tested were changed very little by the inclusion of the data from the remaining four cottons.

It would appear that the gauge length to fiber length ratio q is an important parameter for fiber tenacity. This implies that the tenacity of a proportionate length of a fiber is more significant than that of a fixed gauge length. The parameter is a pure dimensionless number. To those interested in yarn strength where the effective gauge length is substantially constant, this parameter is effectively the inverse of length.

The next most important parameter is s. This represents the "fall off" of tenacity with gauge length and is also a dimensionless number. Although it has been associated with length groups of narrow range, there probably exists some mean value of s associated with a particular mean value of the fiber length L satisfying the above analysis. If so,

$$s = \frac{11.44\,L}{1 - 8\,L} \log T_1/T_0$$

In the most general terms, s appears to represent the over-all disorder in the arrangement of cellulose molecular chains in the fiber.

The change in the disorder or weakness pattern within a boll or variety with the change in fiber length is represented by the parameter r which is again a pure dimensionless number.

The only parameter that is not a pure number is T_0' which is the reference tenacity at 0.0234-in. gauge length of the $1\frac{1}{8}$-in. fiber. This parameter may turn out to be at least partially correlated with the X-ray angle.

The great difference between the maximum and minimum tenacity of 10- or 20-fold implies serious weakness in an otherwise unusually strong fiber. Important improvement in tenacity should be possible. Such improvement, however, may be limited by attendant disadvantages.

Fibers from long staple varieties are generally stronger than the same length fibers from short staple varieties. The disorder or weakness pattern, therefore, would seem to be more favorable in the longer varieties. Breeders seeking strength might do well to start with a foundation of too long staple varieties with a favorable weakness pattern and let the length decrease while selecting for the other desirable characteristics. The favorable weakness pattern, however, must be retained.

6. Acknowledgments

The author wishes to thank the Section of Cotton and other Fiber Crops, Agricultural Research Service, U.S.D.A., and Joel F. Hembree of Cotton Economic Research, University of Texas, for the cottons used in this investigation. Thanks are also due Reba Lawson and Betty Cash for the experimental data and calculations. The author is particularly indebted to C. J. Craven for assistance in the experimental work and interpreting the results.

Literature Cited

1. Peirce, F. T., "Tensile Tests for Cotton Yarns. V. The Weakest Link," *J. Textile Inst.* **17**, T355–T368 (1926).
2. *Rayon Staple in the Cotton Industry*, Courtaulds Ltd. (1948).
3. Sullivan, R. R., "A Theoretical Approach to the Problem of Yarn Strength," *J. Appl. Phys.* **13**, 3, 157–167 (1942).

Sliver Evener for Roving Frames

Hugh M. Brown and John S. Graham

Clemson School of Textiles, Clemson, S.C.

Introduction

Evenness of yarn is one of the greatest concerns in the entire textile manufacturing process. Much care has to be exercised to form picker laps that are uniform from machine to machine and along the lap from each machine. Out-of-size laps are customarily separated and handled differently from those within certain tolerances. Though the variation in sliver caused by the remaining variation in laps is somewhat minimized by doubling and drafting at the drawing frame, there still remains considerable variation in the sliver fed to the roving frame, where this variation occurs again among different slivers and along any given sliver.

In view of this situation, it seems that much could be gained by the use of a device to feed various size slivers into the roving frame at the correct rates to produce a single uniform size roving from all deliveries. Such a device compensating for wide range variations would eliminate the necessity for producing closely-sized laps at the picker, and out-of-sized laps could be run along with the others. Not only would there be a saving in the cost of sliver production but an improvement in the quality of yarn and fabric produced from the evener roving.

A fundamental problem arising in such a system is that since the size of the roving produced is independent of the size of the sliver fed to the roving frame, the size must be determined by constants within the evening device. This requires that the size-determining constants in all units be easy to set and maintain at fairly constant values. Otherwise different size rovings will be produced by different deliveries. Other requirements for an acceptable evening system are that it not be too costly, either originally or in maintenance, and that it be fairly simple and trouble-free.

The problem then is to select a method between those sufficiently elaborate to do a nearly perfect job regardless of cost, and methods that give so little evening that they would not be used however low their cost. The problem might be attacked by having the roving frame deliveries independently driven, but such a solution would probably be too costly. To change the speeds of the input rolls at each delivery could be accomplished either with separate motors or variable speed drives from a common source of power, and either plan would probably be complex and expensive, to say nothing of the problem of maintaining like performance among the various units.

It seems more promising to devise a system having conical input rolls on a common shaft and to move the sliver laterally in relation to the tapered rolls so that it will be fed in at the correct rate to obtain the desired size roving. At first glance this plan may also seem costly but it is believed that conical rolls in pairs (see Figure 1) with a weighted saddle carrying matching pairs of conical top rolls may be justified, assuming a simple mechanism for shifting the sliver can be devised.

This project has been an extended study of several methods for shifting the sliver along the rolls. In some plans the sliver was fed through various types

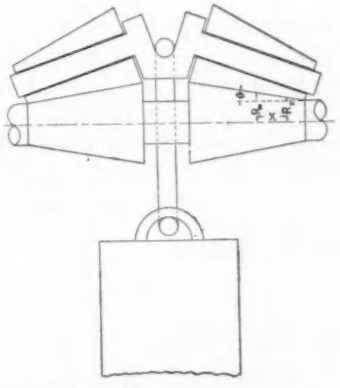


Fig. 1. Conical feed roll system.

of calipering trumpets using the force of the sliver on the walls of the trumpet to position it correctly. Some such forms were built, using first nearly frictionless bearings, and later resilient mountings. Though they seemed to work fairly well, it is believed that the force with which sliver expands a small calipering trumpet gives insufficient power to meet the problem of uniformity among units. It seems that some sort of a servo device is needed to position the trumpet positively. Providing a servo for each delivery could be justified only if it were a simple, low cost mechanism.

Servos operating on the usual electrical or electronic principles are probably too expensive for consideration, and since it is common to have compressed air available in the mills, it is believed a simple mechanical-pneumatic servo can be engineered at a cost that would be justified by the results produced.

Analysis of the Problem

To simplify manufacture, it was decided to use conical rolls having a straight taper. It is obvious that equal shifts of the sliver along the rolls near the small end will produce relatively greater changes in sliver speed than similar shifts near the large end of the rolls. It was decided in the first unit to cover a range in sliver size of ±25%, and to do this the average size sliver cannot be run midway between the two ends of the roll but must be positioned somewhat nearer the smaller end.

Referring to Figure 1, it is clear that the weight of cotton fed per unit time (F) is

$$F = S(2\pi R_x)W$$

where

S = the angular speed of the roll

R_m = the radius of the roll where the mean size sliver is fed.

R_x = the radius of the roll at any distance X along the axis measured from the position of R_m.

W = size of the sliver in weight/unit length.

This can be expressed as

$$F = CR_xW$$

where $C = 2\pi S$. Now

$$R_x = R_m - X \tan \theta$$

where θ is ½ the angle of the cone. Then

$$F = C(R_m - X \tan \theta)W$$

For ideal operation of the device, cotton must be fed at the same weight rate for all sizes of sliver, so that

$$C(R_mW_m) = C(R_m - X \tan \theta)W$$

or

$$X = \frac{R_m}{\tan \theta} \frac{(W - W_m)}{W} = R_m \cot \theta \frac{(W - W_m)}{W}$$

From this equation the theoretical displacement along the rolls from the position for the average sliver can be computed for any size sliver with any roll taper.

Table I shows the theoretical displacement from the mean position using rolls with a half angle of 9.75° and a radius of 0.638 in. for the mean sliver size of 41.6 gr./yd. to cover a range of variation up to ±25%. From this table it is seen that sliver 25% larger than the mean should be shifted toward the small end of the roll a shorter distance than the sliver 25% undersize is shifted toward the large end.

In Figure 2, the dotted curve shows the theoretical displacement required for full compensation for any sliver within the range of ±25%. By compensation is meant feeding the input sliver at a constant weight per unit time.

Several arrangements were tried in which both the movement of the trumpet and the sensing of sliver size were accomplished by means of compressed air. The resulting arrangement which seemed to meet best the ideal curve is a form of pneumatic Wheatstone bridge (see Figure 3) using a bellows differentially in the analogous position of the galvanometer in an electrical bridge circuit.

TABLE I. Theoretical Traverse along Conical Feed Rolls for 100% Sliver Correction

Light sliver		Heavy sliver	
Input sliver, % of mean	Traverse for 100% correction, in.	Input sliver, % of mean	Traverse for 100% correction, in.
1.00	0.000		
0.95	−0.204	1.05	+0.186
0.90	−0.430	1.10	+0.354
0.85	−0.686	1.15	+0.509
0.80	−0.973	1.20	+0.649
0.75	−1.293	1.25	+0.777

The bellows is made amply large so that the differential force caused by different size slivers in the trumpet will be sufficient to move the trumpet and position it positively for feeding in fiber at a nearly constant rate.

If the resistance of the bridge arms R_1 and R_2 is approximately equal to the resistance of arms R_3 and R_x (R_x being the sliver), the response in either direction from the mean is so nearly alike that the correct positioning required for straight conical rolls cannot be obtained. However, by making the resistances R_1 and R_2 much less than the resistances R_3 and R_x, the movement for a given sliver variation on the high side is less than for a similar variation on the low side, and the positioning more nearly follows the curve required for perfect compensation.

In Table II are shown the theoretical displacements of the trumpet with the resistances R_1 and R_2 equal to one-half that of R_3 and R_x, having the air pressure properly matched with the spring constant of the bellows and the leverage ratio of the trumpet arm. Curves for these values are shown by the solid line in Figure 2. The theoretical curves for the rolls and the bridge show that it should be possible to position the sliver for rather good compensation. Later studies showed that still lower values of R_1 and R_2 would give even better correction. The unit is found to work with rather low air flow at approximately 3 lb. pressure. The bridge resistances are easily made of $\frac{1}{16}$-in. tubing, 1 to 4 in. in length. The trumpet, being $\frac{1}{4}$ in. in diameter, is easily threaded.

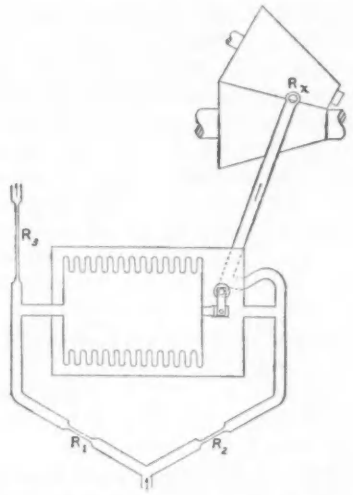


Fig. 3. Pneumatic servo-mechanism for shifting sliver along conical rolls.

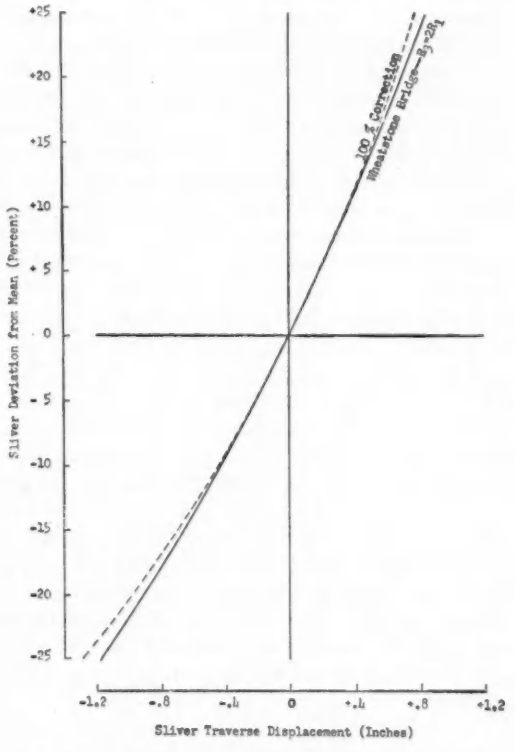


Fig. 2. Theoretical sliver correction for pneumatic Wheatstone bridge traverse.

TABLE II. Theoretical Traverse for Pneumatic Wheatstone Bridge $R_3 = 2R_1$

Light sliver		Heavy sliver	
Input sliver, % of mean	Trumpet traverse, in.	Input sliver, % of mean	Trumpet traverse, in.
1.00	0.000		
0.95	−0.203	1.05	+0.190
0.90	−0.421	1.10	+0.368
0.85	−0.654	1.15	+0.536
0.80	−0.907	1.20	+0.693
0.75	−1.178	1.25	+0.841

The crank arm to which the bellows is attached and the trumpet itself move in arcs instead of straight lines. The lateral displacement of the trumpets would equal the length of the trumpet arm L multiplied by the sine of its angle (θ) measured from the mean position. The angle given the trumpet arm by the bellows is equal to the arc sine of the bellows displacement (d) divided by the radius (l) of the crank arm to which the bellows is attached. The lateral displacement D of the trumpet is then

$$D = L \sin \theta = L \sin \left(\text{arc sin} \frac{d}{l} \right)$$

or

$$D = \frac{L}{l} d$$

Thus the effect of the two angle functions offset each other, and the lateral movement of the trumpet is directly proportional to the displacement of the bellows.

In the above analysis it has been tacitly assumed that the resistance to air flow by the sliver in the trumpet is exactly proportional to the sliver size. It is realized this is not strictly true and that for extremely light or extremely heavy slivers no degree of proportionality would exist.

Another consideration is that the sliver is being drafted between the conical back rolls and the next pair of drafting rolls, and it is well known that actual draft differs somewhat from theoretical draft and this divergence also varies with the size of the back roll. Thus with conical back rolls there would be a variable departure between actual and theoretical draft as the sliver is shifted laterally along the conical rolls.

There are several other minor effects that could be considered, but it was hoped that all the secondary effects might tend to offset each other and not materially reduce the degree of compensation computed from the simple formula used.

Results

Fortunately, in practice, the device gives even better performance than would be indicated by the theoretical curves. Table III shows the variation in output sliver size for input slivers varying from 33 to 50 gr. Each figure in the table is the average of five readings with the range and coefficient of variation shown for each set. The compensation seems exceptionally good in that at no part of the range covered does there seem to be much trend away from perfect correction. Also, note that in all sets of readings the coefficient of variation is less than 1 per cent.

TABLE III. Actual Sliver Correction on Finisher Drawing

Input sliver, gr./yd.	Output sliver, gr./yd.	Range, gr./yd.	Coefficient of variation, %
33.1	31.28	0.7	0.89
36.6	31.52	0.5	0.55
39.0	31.34	0.3	0.33
41.6	31.26	0.6	0.63
46.1	31.30	0.9	0.97
50.7	31.68	0.6	0.73

The above data pertain to the average size of the sliver measured in 1-yd. lengths. Compensation for very short-term variations is not as good. It can be seen that with the sensing element located behind the feed rolls there will always be some overcorrection on the sliver immediately ahead of a change in sliver size, for while the trumpet is moving in response to the new size sliver, it will also effect the draft of that already entering the rolls. This miscorrection is minimized by reducing the sensitivity of the device so that in making a 25% step correction enough time elapses to allow 3 in. of sliver to pass into the rolls. Thus the first $1\frac{1}{2}$ in. of sliver is overcorrected, the following $1\frac{1}{2}$ in. is undercorrected, and any subsequent length of the same size sliver is properly corrected. It seems that this effect is small for all but rapid changes in sliver size.

It should be noted that correction for long-term variations of small amplitude is excellent and that even imperfect correction for large variations is far better than no correction at all. It should also be realized that with the Wheatstone bridge method variations in air pressure do not cause errors with mean-size sliver, though large variations will be overcorrected if the pressure is too high and undercorrected if too low, but here again the corrections, though not perfect, would be in the right direction and would be better than no correction. It is felt that control of the air pressure will not be a serious problem.

To adjust the device for different size slivers, it is planned to have simple interchangeable trumpets that can be quickly inserted in the trumpet arms.

TABLE IV. Actual Sliver Correction on Finisher Drawing

Input sliver, gr./yd.	Output sliver, gr./yd.	Range, gr./yd.	Coefficient of variation, %
41.0	39.40	0.9	0.81
42.2	39.70	0.5	0.52
45.0	40.30	1.0	0.88
46.5	40.22	0.4	0.37
51.6	40.14	0.6	0.52
54.4	40.33	0.1*	0.17*
59.8	39.80	0.5	0.48
61.6	39.10	1.3	1.38
62.4	39.32	1.2	1.12

* Based on three readings.

Runs made with a larger trumpet gave excellent compensation for slivers varying from 41 to 62 gr. (see Table IV). Forty output slivers had a spread of only 1.3 gr. and a maximum coefficient of variation of 1.4%. Here again the results are averages on five 1-yd. lengths. The evenness tester showed reductions in unevenness of approximately one-third.

The device would probably be too costly for use on spinning frames, but by using smaller trumpets the unit worked nicely with rovings. In a large number of tests the unevenness of the output roving was always reduced, the reduction being from very little to one-third, depending on the evenness and type of variation of the input roving.

Incidentally, by placing a pen on an extension of the trumpet arm the movement of the trumpet can readily be recorded on a moving chart. Such charts show that with roving passing through the trumpet at one yard per minute the movement follows almost exactly the trace given by the evenness testers.

This proves that the device does shift the roving in accordance with its size and indicates that this pneumatic bridge method could be used as an evenness meter.

Conclusions

From the progress to date it seems that using the principles outlined it may be possible to develop an evener-mechanism for roving frames sufficiently practical and economical to be justified by its results in terms of yarn improvement and savings in production costs. Use of the device would make close control of picker lap weight unnecessary.

An advantage of this evener is that output sliver size would be essentially independent of moisture regain of the stock, which is not the case when sizing sliver by weighing.

One possible drawback has not been mentioned, namely, that variations in fiber fineness affects the size of the roving produced. It is believed, however, that with modern blending methods this would not materially impair the value of the system.

Acknowledgment

The authors wish to acknowledge the aid of Mr. F. J. Leard, Machinist, who helped carry out the project.

Some Phases of Opening and Picking Evaluation

W. K. Dana

Saco-Lowell Shops, Biddeford, Maine

THIRTY years ago many of the topics under discussion at this Clinic were not only unknown but were unnecessary for the successful operation of a cotton mill. It has been only within the past few years that we became dissatisfied with the evaluation of our spinning by merely weighing a 120-yd. skein, determining the break of this same skein, and then classifying the yarn visually. Even the equipment we used had, in many instances, greater mechanical error than there were variations in the material being tested.

Introduction of electronic apparatus has taken us a long way in the testing of yarns and roving, but not in the opening and picking areas. We have, to be sure, used these same means to check inch-for-inch and yard-for-yard variations in picker laps. We have not, however, done very much in the evaluation of the effectiveness of our opening and picking equipment. With the reductions of processes in a mill, it is becoming increasingly evident that more and more attention must be given not only to the purchase of our raw material, but also to its initial processing. Today, in addition to the cotton classers' staple and preparation evaluation, mills are making their blends based on Micronaire fineness. For this last great step we have Mr. Earl Heard to thank. But what are we doing about fiber maturity and fiber strength in our initial blends? These points and many others all have an important bearing on the operation of our plants, and I feel sure, just as the Micronaire has taken its place, we will also find further tests becoming increasingly important.

We are making only periodic checks of our opening and picking. In most instances this is done quite casually by the overseer or superintendent on his rounds through the mill, and these checks are most frequently inspired by observance of a machine which is not working properly. When something of this kind is noticed, it has been my experience that there follows a flurry of checking on the opening and picking lines. Beaters are reset, grids are adjusted, etc., but as far as evaluating the effectiveness of the machines, nothing is done.

Another common fault lies in trying to get too much production per machine. It seems that very often a machine that is effective at, say, 1000 lb./hr. is highly ineffective at 1200. These factors, however, cannot be determined unless time is taken not only to check the settings but also to evaluate the droppings from each machine. We have many times found ourselves conducting tests which, when complete, were of no practical value because the size of the sample taken, the length of time over which the test was conducted, and the scope of the test were confined to too narrow or too short limits. In many instances, droppings are calculated as a percentage of stock passing through the machine and their character judged by appearance as being o.k., too lean, or too white.

How then should one go about making a meaningful evaluation of cotton preparation? We believe that the first step in any test is to decide what one desires to find out about the process or processes in question, and the second to determine how this can best be evaluated. If a person will sit down and decide what he wants to know and not run a test and then try to determine what he has found out, more conclusive and worth while results will be obtained. We believe that the primary purpose of an opening and picking line is to remove the trash in the bale stock without appreciably degrading the character of the cotton. We also feel that in conducting a test of this equipment one should determine the extent of cleaning in each unit as well as its effect on subsequent machines. This last point is one which is very often overlooked and yet in many instances is the most significant factor.

For this purpose we suggest the use of forms such as those shown (reduced in size) in Tables I, II, and III. It will be seen in Table I that there are spaces for the mechanical details of the machines; there are also spaces to record such items as production rate, running time, droppings in total pounds and in per

cent, and figures from Shirley Analyzer samples. Table II for analysis of the card waste, Shirley Analyzer, and Nep Count is self-explanatory. Table III is a summary sheet.

We have also prepared forms for other machines in the line—feeders, openers, condensers, filters, pickers and card. The forms are all on sheets 8½ by 11 in. These forms constitute a complete cotton cleaning survey and can be employed as desired for obtaining information on operating conditions.

Figure 1 compares graphically two opening and picking lines. With the exception of Operation 4, both have identical machinery. Across the bottom of the chart the numbers represent individual machine operations, where waste is removed or collected, in numerical sequence in the direction in which the stock passes through the line. The vertical scale represents per cent of potential trash removed. The vertical bars compare the two lines at each stage of operation. The hashed bars are for line 1 and the solid bars line 2.

TABLE I

Sheet No. .....

COTTON CLEANING SURVEY

Mill .....

Date .....

F-7 Feeder	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
Doffer R.P.M.						
Comb Speed						
Comb Set						
Combing Roll R.P.M.						
Combing Roll Set						
Grid Box under Doffer						
Adj. Grid Bar under Doffer						
Adj. Grid Bar Set						
Dia. Feed Pulley						
Production						
Time Run						
Pounds Run						
Total Droppings (Lbs.)						
Waste Per cent						
Shirley: Sample Wgt.						
% Lint						
% Trash						

# 15 Opener	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
Beater R.P.M.						
Beater Set						
Adj. Grid Bars #1 Set						
Adj. Grid Bars #2 Set						
Adj. Grid Bars #3 Set						
Total Droppings (Lbs.)						
Waste Per cent						
Shirley: Sample Wgt.						
% Lint						
% Trash						

TABLE II

Sheet No. .....

CARD WASTE TEST

Lap Weight (Gross) ..... Lbs.
Less Lap Rods ..... Lbs.
Total (Net) ..... Lbs.
Less Lap Waste ..... Lbs.
Total Fed ..... Lbs.

Waste: Lickerin ..... Lbs. ..... %
Fly ..... Lbs. ..... %
Flat Strips ..... Lbs. ..... %
Cyl. & Doffer Strip ..... Lbs. ..... %
Total Visible ..... Lbs. ..... %
Invisible ..... Lbs. ..... %
Total ..... Lbs. ..... %

Card Sliver Weight:

	Gross	*Can*	*Net*

Total ..... Lbs.
Plus Sliver Waste ..... Lbs.
Total Delivered ..... Lbs.

SHIRLEY ANALYZER

	Sample Wgt.	*Lint*	*Trash*	*% Lint*	*% Trash*
Lickerin Waste					
Cyl. Fly					
Flat Strips					
Cyl. & Doff. Strips					

NEP COUNT

R. H. of Web	*Web. Center*	*L. H. of Web*

Avg. (per 100 sq. in.) .....

The lines running diagonally up the chart from lower left to upper right represent the cumulative per cent of trash removed through each stage of operation.

If this evaluation had been concluded after operation number 4, it might easily be assumed that the two different machines used on this operation were interchangeable and comparable. This would be a fine example of a test confined to too narrow limits as the balance of the graph clearly indicates. Line 1 has a total cleaning efficiency of 50.8% whereas line 2 has a total of 67.3%. In this particular instance the total droppings in each line were equal and no change in nep count was observed, indicating that the change in operation 4 in line 2 was giving a valid improvement.

We should not stop our checking after we have completed an evaluation of this kind; for all practical purposes, we have only established a base from which

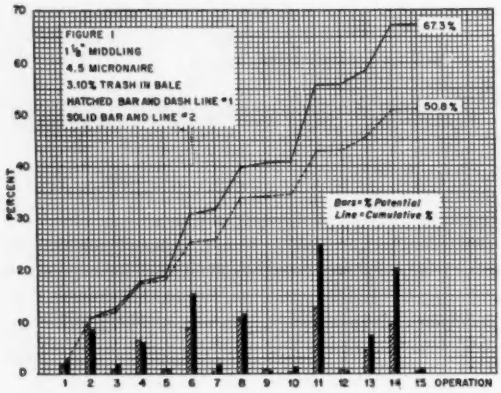


Fig. 1. Comparison of efficiency of two opening and picking lines.

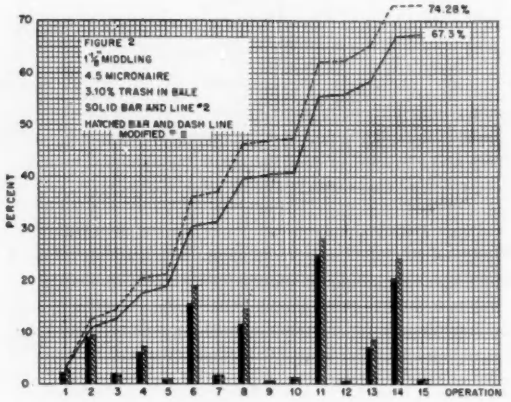


Fig. 2. Dash bar and line show increase in efficiency of opening and picking line 2 after modification.

to work. Changes in speeds and settings should be investigated.

The chart in Figure 2 compares line 2 of Figure 1 with the same line after some changes have been made. In this instance adjustments were made to increase the total droppings on operations 1, 2, 4, and 6 by 50%. The increase of droppings was not all trash but as might be expected had an additional proportion of lint. However, the final cleaning efficiency rose from 67.3 to 74.28%, or about 10% improvement. This comparison is given for illustration purposes, and not as one necessarily to be followed. Many times, however, the taking of additional lint in the opening and picking line droppings has reduced fly to a marked degree in the balance of the mill.

Tests of this kind take a great deal of time, not only in collecting the samples, but also in evaluating them. It is because of this time factor I believe that more testing of this kind is not done. It has been found, however, that just as we check yarn in the spinning room, it is possible, once having established standards, to continue to check individual units against these standards. In this way each individual mill will not only be able to build up a backlog of information which will be invaluable, but will also be able to detect very quickly any troubles which might be found coming in their spinning and weaving areas.

TABLE III. Summary Sheet Requirements

1. Machine identification
2. Gross weight of stock run in test
3. Gross weight of trash in stock
4. Per cent trash
5. Gross weight of droppings
6. Droppings as per cent of production
7. Weight of lint in droppings
8. Per cent lint in droppings
9. Invisible loss per cent
10. Weight of trash in droppings
11. Per cent trash in droppings
12. Per cent of potential trash removed
13. Cumulative per cent of trash removed

Letters to the Editor

Some Observations on the Chemical Antifelting Reaction for Wool

Department of Textile Industries,
Technical College,
Bradford, England
January 11, 1957

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

Of the many reagents which impart resistance to felting when they are applied to wool from aqueous solutions, chlorine in the free state, i.e., in acid solution, is by far the most effective. It degrades the fiber surface, and after milling, microscopical examination shows that the scales are greatly modified, or even completely removed. Other powerful oxidizing agents such as potassium permanganate, sodium hypochlorite [1] and chlorine dioxide are less effective than free chlorine. They produce less scale modification, and under drastic shrinkage conditions, such as in milling stocks or the use of an acid milling medium, fabric treated with these reagents felts. From the practical viewpoint, however, the very effectiveness of free chlorine in degrading the wool fiber often produces undesirable features, such as poor handle, high weight loss, and high solubility in alkali of treated goods, and sodium hypochlorite alone, or in admixture with permanganate, is used widely.

All strong oxidizing agents rupture the disulfide bond of the cystine residues of wool keratin, and Speakman [7] considers that this alone is sufficient to render wool nonfelting; provided it is not accompanied by the formation of new cross-linkages. Alexander et al., on the other hand, have shown that, in addition to breaking this bond, effective antifelting agents also oxidize tyrosine residues [1].

Some explanation for the fact that hypochlorite and alkaline solutions of permanganate are inferior to free chlorine as antifelting agents has been found, since there is evidence that the former reagents convert cystine residues in wool to lanthionine [2], and therefore, new stable cross-linkages are introduced into the wool structure. However, the inferiority of acid solutions of potassium permanganate and chlorine dioxide remains unexplained.

During an investigation into the action of a number of oxidizing agents on silk fibroin, unexpected results were obtained. It had been anticipated that these would bring about main-chain degradation, which would reduce the viscosity of solutions of the oxidized protein. It was found, however, that a number of these agents rendered much of the fibroin insoluble in solvents for silk, such as cupri-ethylenediamine, phosphoric acid, and calcium chloride in formic acid [4], while chlorine in acid solution produced no such effect.

[1] Chlorine and sodium hypochlorite are normally applied to wool by exhausting a given weight of available chlorine onto the wool. Although it is possible to increase the effectiveness of hypochlorite by immersing the wool in a concentrated solution for a short time [6], under identical reaction conditions free chlorine is the more effective reagent.

TABLE I. The Reaction of Fibroin with Chlorine, Hypochlorite, Permanganate, and Chlorine Dioxide

Reagent	pH	% Insoluble in $CaCl_2$/formic acid	
		3% oxidizing agent	10% oxidizing agent
Cl_2	1.4	5.7	4.5
NaOCl	9.2	31	77
$KMnO_4$	1.4	27	43
$KMnO_4$	9.2	44	57
ClO_2		92	92

This work has been reported in detail elsewhere [5, 8], and a summary of the results obtained is given in Table I.

The quantities of oxidants are given as their percentage weight on the weight of fibroin. Hypochlorite was determined as available chlorine.

It is seen that, apart from chlorine in acid solution, the oxidizing agents which are used as antifelting agents are not effective in degrading fibroin. On the contrary, they actually render it insoluble in the usual solvents. It is particularly noteworthy that the very powerful oxidizing agent, chlorine dioxide, one of the least effective agents for producing resistance to felting in wool, is the most effective for insolublizing fibroin.

It has not been possible to determine with certainty the reason for the insolublization of silk fibroin by oxidizing agents, but Cadwallader and Smith [3] and Earland and Stell [5] have concluded that the evidence points strongly to its being due to cross-linking, via tyrosine residues.

The object of chemical antifelting is to disperse or gelatinize the surface of the wool fiber in the felting medium, and it is quite possible that an effect similar to that occurring with silk accounts for the variation in efficacy of the different antifelting reagents. In this event, many agents while oxidizing cystine and tyrosine residues, at the same time are introducing new cross-links into the keratin structure. It is well known that the effectiveness of an antifelting reaction is reduced if it is accompanied by the formation of new cross-links. It must be concluded that chlorine in the free state either oxidizes tyrosine residues in a specific manner, such that no cross-links can be subsequently formed, or it produces general degradation of the keratin structure which outweighs any effects of cross-linking.

The views presented here are not put forward as being conclusive, since the proteins of silk and wool possess obvious dissimilarities, such as main-chain configuration, and it does not necessarily follow that a reaction which cross-links one protein will necessarily cross-link the other. On the other hand, the two proteins do undergo many common cross-linking reactions. These views do, however, provide an explanation for the hitherto unexplained fact that the ability of a reagent to render wool nonfelting is unrelated to its oxidizing power, e.g., the inferiority of chlorine dioxide compared with chlorine for this purpose.

Literature Cited

1. Alexander, P., Carter, D., and Earland, C., *J. Soc. Dyers Colourists* **67**, 23 (1951).
2. Alexander, P., Fox, M., and Hudson, R. F., *Biochem. J.* **49**, 129 (1951).
3. Cadwallader, C. J., and Smith, S. G., *J. Textile Inst.* **47**, T489 (1956).
4. Earland, C., and Raven, D. J., *Nature* **174**, 461 (1954).
5. Earland, C., and Stell, J. G. P., *Biochim. Biophys. Acta* **23**, 97 (1957).
6. Milton Harris Associates, U.S. Pat. 2,466,695.
7. Speakman, J. B., Nilssen, B., and Elliot, G. H., *Nature* **142**, 1035 (1938).
8. Stell, J. G. P., *M.Sc. Thesis,* London University (1956).

CHRISTOPHER EARLAND

Book Reviews

The Mechanical Properties of Textile Fibres. Edited by R. Meredith, Interscience Publishers, Inc., New York; North-Holland Publishing Company, Amsterdam, 1956. 333 pages. Price $8.75.

Reviewed by Joseph H. Dusenbury, Textile Research Institute, Princeton, N.J.

This book is one of the monographs in the Interscience "Deformation and Flow" series under the joint editorship of J. M. Burgers, J. J. Hermans, and G. W. Scott Blair. It is a review of previously published work on the mechanical properties of fibers and other related subjects. There is an introductory chapter on fiber structure, following which the remaining chapters are divided into three major sections. These sections, which are essentially independent of one another, are concerned with cellulose, protein, and synthetic fibers, respectively.

Part A, "Cellulose Fibers," by R. Meredith, consists of the chapters: The Structure of Cellulose Fibers, Relaxation and Creep, Stress-Strain Relations, Reaction-Rate Theory, Dynamic Mechanical Properties, and Fiber Strength. Part B, "Protein Fibers," by L. Peters and H. J. Woods, contains chapters on The Structure of Protein Fibers, Creep and Relaxation, Load-Extension Curves, Setting Effects, Equilibrium Theory, and Kinetic Theory. Part C, "Synthetic Fibers," by R. Meredith, consists of these chapters: The Structure of Synthetic Fibers, Creep and Relaxation, Stress-Strain Relations, Dynamic Mechanical Properties, and Resilience and Creasing. All the references are listed after the final chapter in a single bibliography section, and there are short but adequate author and subject indices.

The four plates, located together prior to the introductory chapter, contain X-ray diffraction patterns of the materials to be discussed subsequently, and while this is admittedly a minor criticism, the reviewer would have preferred to see a particular set of fiber diffraction patterns located in the corresponding chapter on fiber structure. The introductory chapter, by L. Peters and H. J. Woods, considers such general matters as fiber crystallinity, the differences between fibers and rubbers, and the thermodynamic picture of what happens when a fiber is stretched. Although brief, this chapter is well-written, and should be required reading for those interested in learning more about the mechanical behavior of fibers. In fact, the entire volume is well-written, and the consequent easy readability should aid in its gaining a wide audience.

The organization of the book causes a fair amount of repetition. This, however, is offset to a great extent by the advantage of having consecutive discussions of the mechanical properties of each of the three major classes of fibers considered. The chapter on Reaction-Rate Theory in the section on cellulose fibers constitutes a summary of the papers by Eyring and co-workers, which deal with the application of the absolute reaction-rate theory to the mechanical behavior of fibers and the resulting famous hyperbolic sine law. In this and in a subsequent chapter on Kinetic Theory in the section on protein fibers, the absolute reaction-rate theory has been presented in a way that implies the theory has provided a rather complete explanation of fiber behavior. This seems to this reviewer to be unfortunate. The presentation in this fashion, without criticism or discussion of alternative explanations, serves to mar an otherwise excellent volume.

The figures and tables in the book are well-chosen and instructive, and the format is attractive. In the Preface, dated April 1955, Dr. Meredith mentions that much work has been done on the mechanical properties of fibers during the last decade and that it is hoped that this monograph will provide an up-to-date summary of much of this work. This hope appears to have been fully realized.

Advances in Carbohydrate Chemistry, Vol. IX. Edited by M. L. Wolfrom. Academic Press, Inc., New York, 1954. 426 pages. Price $10.50.

Reviewed by Eugene Pacsu, Princeton University, Princeton, N.J.

This is the first volume of the "Advances" under the sole editorship of M. L. Wolfrom after the death of C. S. Hudson, former co-editor and one of the founders of this valuable reference work. An obituary of Claude Silbert Hudson written by Dr. Wolfrom represents a befitting memorial to a great leader

whom carbohydrate chemistry lost in 1952. An excellent photograph of "Huddy" serves as a frontispiece to the book.

The text of the volume contains nine comprehensive articles by eleven authors, one British, one Canadian and nine American, on the following subjects: "Some Implications in Carbohydrate Chemistry of Theories Relating to the Mechanisms of Replacement Reactions," by R. U. Lemieux (132 references); "Alkali-Sensitive Glycosides," by Clinton E. Ballou (71 references); "The 2-Hydroxyglycals," by Mary Grace Blair (61 references); "The Methyl Ethers of Hexuronic Acids," by G. O. Aspinall (78 references); "The Raffinose Family of Oligosaccharides," by Dexter French (105 references); "The Conjugates of D-Glucuronic Acid of Animal Origin," by Robert S. Teague (265 references); "Color and Turbidity of Sugar Products," by R. W. Liggett (88 references); "Carboxymethylcellulose," by J. V. Karabinos and Marjorie Hindert (155 references); "Paper Chromatography of Carbohydrates and Related Compounds," by George N. Kowkabany (216 references).

An author index (18 pages) and a subject index (50 pages) contribute to the ease of locating pertinent references. It is particularly commendable that the editor has brought the carbohydrate nomenclature employed in this volume into conformity with the rules published in *Chemical and Engineering News*, **31**, 1776 (1953).

Advances in Carbohydrate Chemistry, Vol. X. Edited by M. L. Wolfrom. Academic Press, Inc., New York, 1955. 437 pages. Price $10.50.

Reviewed by Eugene Pacsu, Princeton University, Princeton, N.J.

With this new volume of the series an impressive row of ten issues are now available for reference in the broad field of carbohydrates. In view of the countless number of publications dealing with these compounds and derivatives and appearing every year in a great many scientific journals, it is gratifying to know that the student of the discipline can quickly receive detailed, authoritative, and up to date information on the various subjects of particular interest to him. This volume represents another valuable addition to the growing family of the "Advances" and its contents conform uniformly to the high standards set by the editor for the quality of the contributions.

This is the third consecutive issue in which the reader finds an obituary, this time that of Edmund George Vincent Percival, whose death at the early age of 43 has deprived carbohydrate chemistry of an enthusiastic and able leader. E. L. Hirst and A. G. Ross have written the lines in memory of the British scientist, at one time one of the Birmingham School collaborators participating in the determination of the constitution of vitamin C.

In this issue the following topics are discussed: "The Stereochemistry of Cyclic Derivatives of Carbohydrates," by J. A. Mills (210 references; "Column Chromatography of Sugars and Their Derivatives," by W. W. Binkley (196 references); "Glycosylamines," by G. P. Ellis and John Honeyman (238 references); "The Amadori Rearrangement," by John E. Hodge (98 references); "The Glycosyl Halides and Their Derivatives," by L. J. Haynes (275 references); "Polysaccharides Associated with Wood Cellulose," by W. J. Polglase (217 references); "The Chemistry of Heparin," by A. B. Foster and A. J. Huggard (133 references). The revised set of tables of the physical characteristics of "The Methyl Ethers of the Aldopentoses and of Rhamnose and Fucose," by George G. Maher, and a similar set involving "The Methyl Ethers of D-Galactose" by the same author replace the respective tables published in earlier issues of the "Advances" and bring the subjects up to date.

An author index (21 pages) and a subject index (44 pages) complete the volume. Publication of a decennial author and subject index would be most desirable to those using this splendid reference work.